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SciLit
SCIENTIFIC LITERACY AT THE SCHOOL

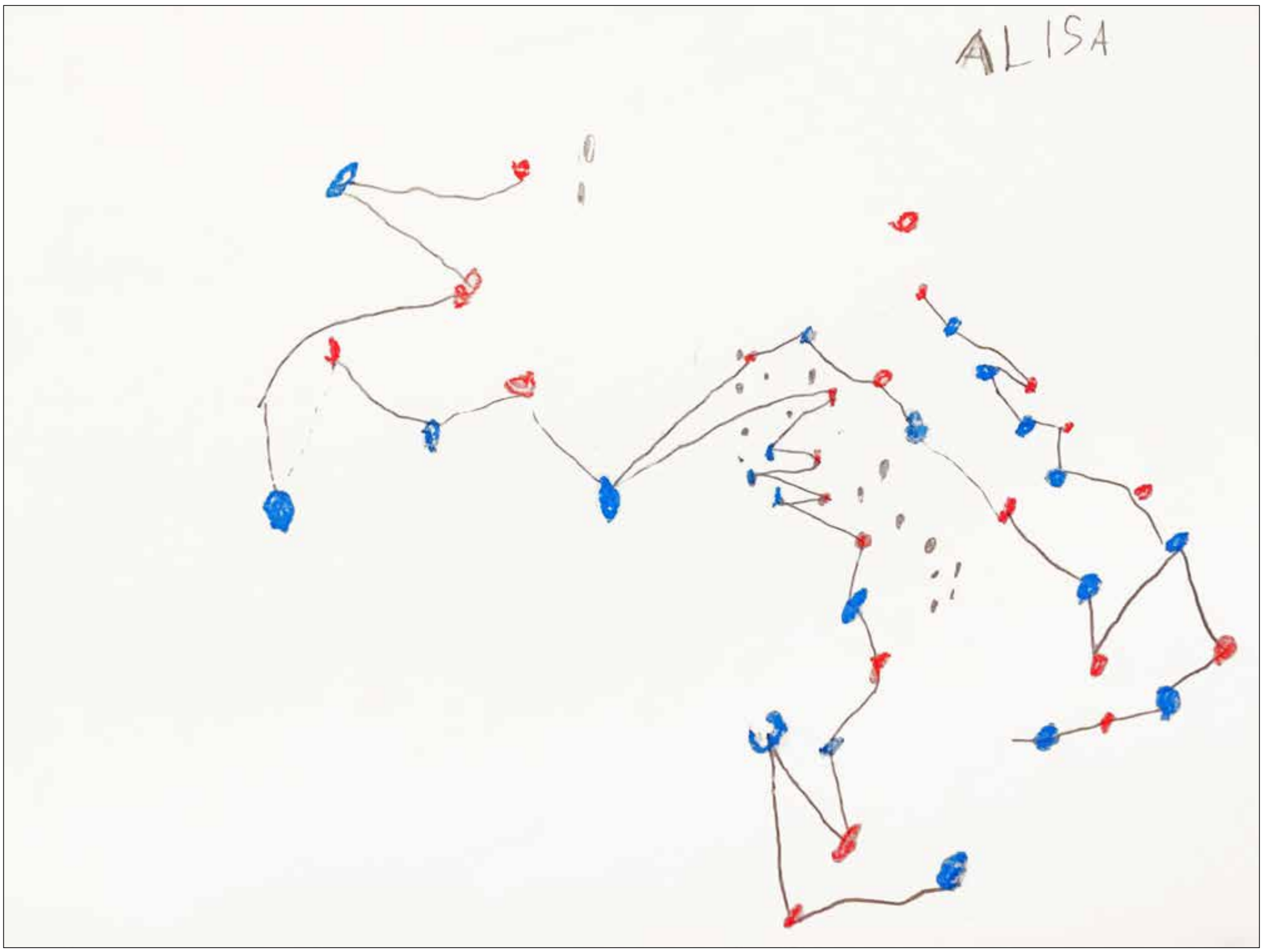
Scientific literacy at the school. An inquiry about *What is the world made of?*

Scientific literacy at the school: Improving strategies and building new practices of science teaching in early years education (SciLit)

2016-1-ES01-KA201-025282

CSIC Consejo Superior de Investigaciones Científicas
El CSIC en la Escuela Vicepresidencia Adjunta de Cultura Científica
Kujawsko-Pomorskie Centrum Edukacji Nauczycieli w Bydgoszczy
CPR Gijón Oriente
cesie the world is only one creature
Przedszkole nr 34 w Bydgoszczy Mali Odkrywcy
Asunduse Lasteaed

When students become aware of the process by which they understand phenomena with the help of mental models, the use of these models to explain new phenomena and how attractive and fun scientific research is, we can consider that they have acquired what we call scientific literacy.



Intermolecular forces between water molecules as seen by a 5 year old child.

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INTRODUCTION

INTRODUCTION

This teaching guide has come out of the joint work of CSIC scientists and educators from Estonia, Lithuania, Poland, Italy, and Spain, which established a network of constant communication in order to implement innovative practices in science teaching for early educational stages. It is likely that the success of this collaboration is due to the way human beings are attracted to the processes of discovery and exhibiting their new knowledge, as well as learning and teaching what they have found out: this is the essence of our nature, particularly in childhood. Indeed, teachers and scientists feel this attraction most strongly, and we are lucky to have them aboard in this project.

We are all touched when we see how young boys and girls, of four and five years old, discover that water travels invisibly through the air, but becomes visible when it condenses on the cold glass of a window. They effortlessly accept that the form it travels through the air in, which is necessarily very small, is called a molecule.

In this work, we have considered the criteria of diversity in education, including the issues of gender and cultural difference, as well as the children's development of a critical attitude as they learn about science.

The process of learning science in many cases includes the assimilation of a culture. The nature of science makes it different from other disciplines, as it is based on the independence of criteria and creativity; it has its own way of looking at the world, as well as particular values, procedures and language. Because of this, it is increasingly necessary to update the scientific training of the teaching staff and innovate new educational methods. Teaching science in the early educational stages is fundamental for later studies if an appropriate method is established by means of experimental work.

The implementation of these innovative practices in the teaching centres participating in the Erasmus+ project was based on three key elements:

A. *The scientific training of the teaching staff by CSIC at School*, equipping them with a core of scientific knowledge to help them tackle the innovative practices in their classrooms.

B. *Investigation of the learning processes*, enabling an analysis of the way pre-school and primary students conceptually process and mentally represent nature. Teaching pre-school and primary science requires a very precise knowledge of the sequence of cognitive stages. For this reason, simple experiments have been designed that are adapted to these stages. They show the way the process of investigation (inquiry) leads to the discovery of laws, theories, and models relating to certain phenomena we can observe in our daily lives, like water evaporating from clothes hung out to dry, or water appearing on the surface of a very cold can.

C. *This guide has been created as a result of this training and research process*, as a tool for teaching staff in partner countries. It presents science as a method for solving problems, facilitating the students' overall development, while also being a key element in the scientific literacy of the general public.

Description of the project: What is the world made of?

We have been able to investigate the capacity of children to visualise the world they cannot see with their eyes, so all the activities described below deal with the difference between the macroscopic and microscopic worlds. We discover how the world works and what it is made of, in other words, we set off on a journey through the matter that appears to us in the solid, liquid, gas, and plasma states.

In the research the students do, they find out what water is made of, what forces act when a drop sticks to another substance, what happens during evaporation, and how a paper clip can be supported by water. In this way they discover, in a simple manner, that the world is made up of atoms, molecules and crystals that our eyes are not able to see but which are real, and we have to understand how they work.

Scientific knowledge for teachers

Some prior considerations.

Taking water as a case study, through simple experiments and appropriate questions, the students begin to conceptualise the relevant magnitudes that determine the elastic and adherent behaviour of water in its liquid state, and they are able to elaborate an elastic surface model that explains this behaviour.

This guide presents a training unit for early educational stage teachers that deals with intermolecular forces, which are those largely responsible for the appearance and mechanical behaviour of materials.

The scientific knowledge described below is divided into three parts:

1. The first deals with the physical properties of water resulting from intermolecular forces. It uses the questioning technique (*inquiry*), with the aim of indicating the way researchers work through experimenting and building knowledge. In the questioning technique, we must provide a reason for the behaviour of the water surface, as well as for the changes of state. These problems are solved using the molecular model of matter, where we represent the water molecules as sub-microscopic elastic spheres and postulate intermolecular forces of nature that are, initially, unknown. We soon discover that these forces are electrical, and we are forced to make a quick detour through the history of that discipline.

2. In the second part, we rapidly cover the history of electricity relevant to molecular theory and which explains Van der Waals forces, those responsible for the phenomena under investigation. The reason we take this route is so that the teachers realise the difference between simply listing historical facts and a constructivist interpretation of the history of science.

3. The third part deals with how we use the laws of electricity to explain the nature of intermolecular forces. We approach this section from the perspective of a 21st century scientist when studying the history of the science of previous centuries. Current knowledge allows researchers to interpret discoveries made throughout

history according to up-to-date models and theories. This situation mimics what teachers will find in their classrooms since they will have to guide their students along a constructivist pathway from a much more advanced position, both with regard to knowledge and a panoramic view of the way this knowledge has been constructed. In this way, once the students understand the laws of interations between charges, and by modifying the spherical molecule model, we can qualitatively explain the results of the experiments we have done.

Finally, this guide shows how teachers from different countries have used this method to teach science in their classrooms, once they had received the necessary training.

In summary, this guide aims to be a useful tool to help any early educational stage teacher bring science into their classroom.

Erasmus+ SciLit project partners.

FIRST PART

SCIENTIFIC DESCRIPTION OF THE GUIDE

I. FIRST PART: INTERMOLECULAR FORCES

The majority of the phenomena, transformations, and behaviour of the materials that make up the daily lives of the students are due to the effects of intermolecular forces, whose nature is, as we will see, electrical.

To understand these forces, we have developed a teaching pathway that begins by observing water's elastic and adherent properties when in contact with solid surfaces. Based on the experimental results we have obtained, together with the existence of three states of matter (solid, liquid, and gas), we will try to imagine a model that explains how the same substance can appear in three forms with such different physical properties. To find this out, we choose water as our *case study*, as it is the only easy-to-find substance that appears in these three states at room temperature.

1.1. DAILY SITUATIONS

It is clear that the first step in our approach to a research project at this level is to observe natural phenomena. From here, we should focus on the innumerable examples of drop formation that can be found both in the classroom and our surroundings (Figures 1 and 2). We ask the students to use their lab books to describe and draw the phenomena related to the drops of water, adding comments and indicating the facts they consider most interesting.

Based on the notes in their lab books, each student should explain, in their own words, what they have represented in their drawings. These conversations provide information on the concepts they can handle, the preconceptions they have, and the focus of interest in their way of looking at the world.

Figure 1. Water drops on a leaf.

Figure 2. Water drops falling from a tap.

The relevant concepts in the observations we are talking about are the tendency of the water to adhere to the solids it comes into contact with, the way the drops resist splitting up, the shape the water acquires, and how important the weight of the drop is in the processes of falling off.

1.2. EXPERIMENTATION

Once they have thoroughly studied natural phenomena, scientists design experiments that they then carry out in their laboratories, in order to look more closely at the phenomenon that interests them. To do this, they must eliminate any non-essential elements in the process and use apparatus that allows them to modify the parameters they want to control.

The first experiment we will carry out consists of studying what happens when we hold a small amount of water between our index finger and thumb (Figure 3). This allows us to *feel* the elastic behaviour of the water, contrasting its tendency to adhere to our fingers and the propensity of the water to remain together, without dividing into two. The first property we will call **adhesion** and the second, **cohesion**.

Figure 3. A water drop between the index finger and the thumb.

The first thing that occurs to us is whether these tendencies depend on the nature of the liquid and the solid with which it is in contact. The students will quickly suggest, depending on their age, appropriate experiments for testing this: using gloves of various non-absorbent materials and different liquids, like oil, salt water, washing-up liquid, and so on (never flammable, of course).

Next, we can study the drop formation process in slow motion, using a plastic dropper or plastic needleless syringe (Figure 4). With skill, we can determine the moment the drop detaches and, if we use the same liquids as in the previous experiment, we can get an even more precise idea of the importance of this in the process.

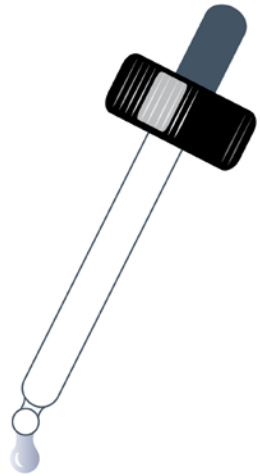

Figure 4. Dropper.

Why do different syringes or droppers produce bigger or smaller drops? To quantitatively determine the size of the drops we can weigh or measure the volume of a sufficiently high number of them —two hundred, for example.

To *pin down* nature yet further and force it to reveal its secrets, we can construct inclined planes of different materials and determine the slope at which a drop starts to slide downwards.

It is very interesting to repeat these experiments on surfaces made of aluminium foil or cling film (transparent polyethylene), waxed or oiled paper, and so on. This will show how important the nature of both the liquid and the solid surface on which it slides are (Figures 5 and 6). We should study these processes and carefully note down the results in our lab books.

A particularly relevant question to discuss in class is whether the angle at which the sliding begins depends on the size of the drop or not. This is an important point, and to determine the answer we will have to carry out a series

Figures 5 and 6. Water drops on various materials with different slopes.

of different experiments, using what we have learned in the process of forming drops with the syringes. We can always put a drop formed from two or even three drops from a specific dropper on a flat plane, since due to cohesion they always tend to join together into a single drop. This observation should be directed to students in primary education who have looked at the concept of angles.

1.3. TIME TO INTRODUCE THE CONCEPT OF FORCE

In order to understand the phenomena that take place between liquids and solids it is essential to use the concept of force. Contrary to what one might think at first, the concept of force corresponds to an abstraction of a higher level than that of the concepts we are using.

We already know that defining a concept is a virtually impossible task. Concepts are formed in the mind by a poorly understood process known as conceptualisation, for which human beings are especially well adapted. When we learn to speak, what we do is link a concept (dog, cat, person, brother, to take, to bring, pretty, ugly, etc.) with a word, so that when we hear or read the word it evokes in our mind the associated concept. The association of a sound or written word (or any type of symbol) with a concept is what we call meaning (Figure 7).

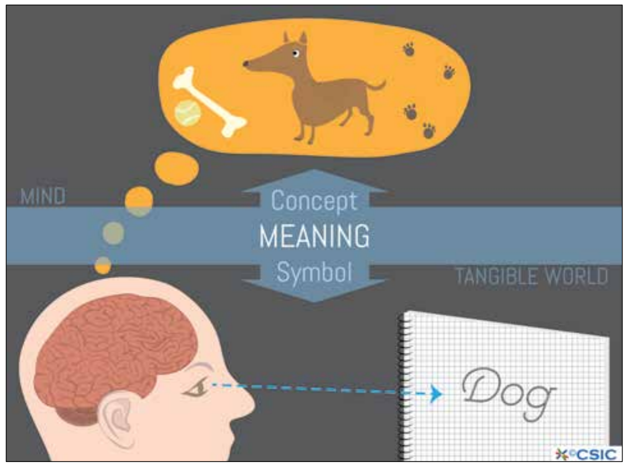

Figure 7. Meaning.

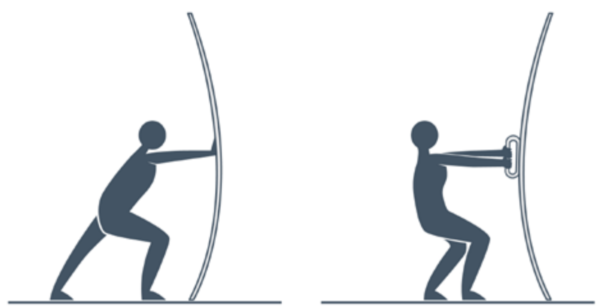

Figure 8. Pushing and pulling forces.

In order to start conceptualising the meaning of force in physics, we can say that it is any pushing or pulling of one object caused by the action of another (Figure 8). In this case we can say that the two objects are interacting (there is an action between them).

There are various types of forces, those that need the objects to be in contact, like the ones shown in the figure, and those that act at a distance (without the need for physical contact), like magnetic, electrical, and gravitational forces, which the students should already know about. If this is not the case, now is the time for the children to play with magnets, straws and balloons rubbed with paper napkins, or pick up weights from the floor (Figure 9).

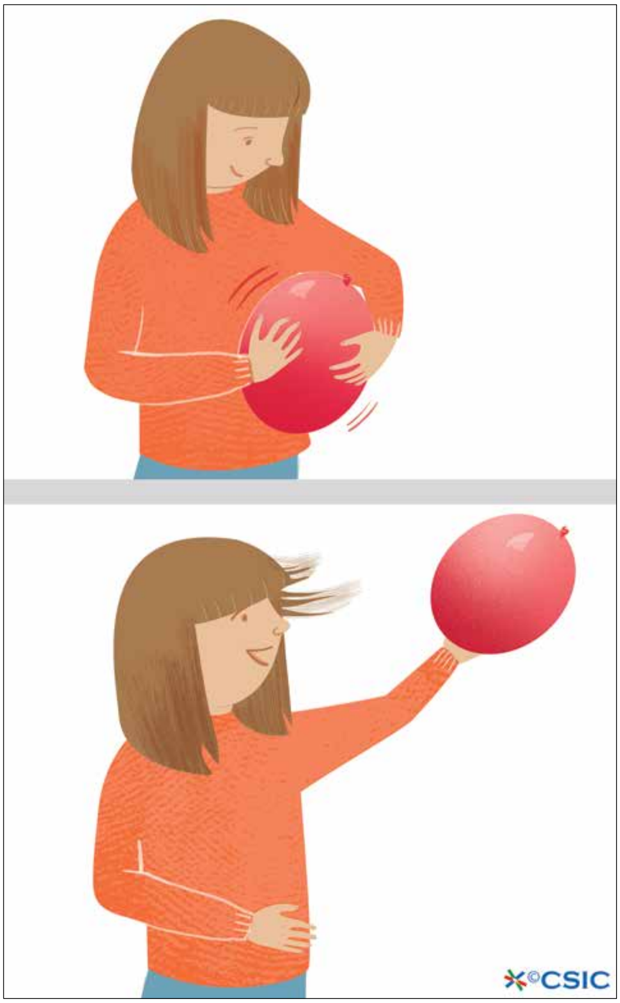

Figure 9. Electrostatic forces in a rubbed balloon.

Whenever a force acts on an object, it produces movement or deformation. If we kick a ball, it moves as a result of the force the shoe has exercised on it during the time they were in contact. In contrast, when we stretch a spring or compress a ball, we deform the objects. When an elastic object, such as a bow, deforms, it produces an elastic force (Figure 10).

Figure 10. Elastic force in a drawn bow.

To assimilate these new concepts we can do a simple experiment that all the students should carry out. It is believed that Leonardo da Vinci was the first to represent the concept of force through an arrow whose length was proportional to its magnitude, with its direction and sense corresponding to the direction and sense of the force[1].

To introduce the concept of force we can carry out the experiment depicted in Figure 11.

The magnetic force the magnet exercises on the paperclip is magnetic in nature and acts at a distance. Its direction is the straight line that joins the pole of the magnet and the paperclip, and its sense is that which goes from the clip to the magnet. The weight of the clip is another force that acts vertically, and its sense is towards the surface of the Earth. Also acting is the

[1] In the Codex Arundel there are several illustrations that represent the low of composition of forces.

elastic force of the thread, which by deforming (stretching) exercises a force whose direction is that of the thread and whose sense goes towards the point where the thread is attached to the table, and which is of contact type. There are many other forces in the experimental set up, but we will only consider those mentioned. Therefore, three forces are acting on the paperclip, with distinct origins and of different types. But the fact that it is not moving indicates that when you sum three forces (their nature is the same), the result is null.

Figure 11. How many forces are acting in this experiment?

From this experiment we have learned that forces occur between two bodies, either through contact or by acting at a distance. When a body is in repose (i.e., not moving), it is because there are no forces acting on it, or because the sum of the applied forces is null. With this new concept we can describe experimental concepts more easily.

Drop formation

If we pay close attention to the phases of drop formation (Figure 12), we can see that two forces are acting: firstly the weight of the drop (a vertical and downwards force), which tends to detach it from the end of the dropper; and, secondly, the force that keeps it stuck onto the dropper (force of adherence, vertical and upwards). When the weight of the drop exceeds the force of adherence, it detaches from the dropper. If we do experiments with droppers that have different-sized ends and we weigh a high number of drops, we will see that the weight of each of them is, very approximately, proportional to the diameter of the end.

Figure 12. Observing adhesion and cohesion forces.

Once the force of adherence has been identified, we can ask ourselves why the drop does not break into thousands of droplets, instead of staying more or less spherical, as large as possible, keeping the water in a cohesive shape.

Constructing a drop model

With the aim of understanding the mechanism behind drop formation, we can imagine that the water has some kind *of slightly sticky skin* (to explain the adhesion), which always surrounds it and which is responsible for the formation of drops at the end of a drinking straw, tap, or in a spider's web (Figure 13).

This *skin* surrounds the rest of the liquid and gives it the observed properties (Figure 14). In addition, the skin we are referring to also adheres to solid objects that come into contact with the liquid, like the mouth of a tap, and the drop only detaches when the weight becomes greater than the adhesion force: this depends on how sticky the *skin* is.

Figure 13. Drops *stuck* to a spider's web.

Figure 14. The skin of a balloon full of water is a good analogy of the surface tension.

If we repeat the drop between thumb and index finger experiment (see previous Figure 3), we can describe the process of rupturing the drop as the breaking of the elastic skin. As this results in the formation of two smaller drops, each adhered to a different finger, we must conclude that the force of adhesion between the water and skin is greater than the force of cohesion, represented by the resistance of the drop's skin to breaking.

The model we have constructed is *analogical*, as we have assumed that what happens is *analogous* to what would happen if any part of the water were covered by an elastic skin, like that of a balloon. This corresponds to that which Piaget calls *mental representation*. As we will see, even a model as simple as this, constructed ad hoc to explain what happens in drop formation, can be extended to other situations and help us understand many other processes. This indicates how useful constructing models or representations is for understanding the world, in other words, as a form of knowledge.

Extending the elastic, sticky skin model to explain other observations: process of assimilation

Next, we will test our elastic, sticky skin model for water in various situations, other than for the formation of drops for which we constructed it. The first opportunity comes from observing certain insects that support themselves or move around on the surface of water, as if it were the surface of a solid (Figure 15).

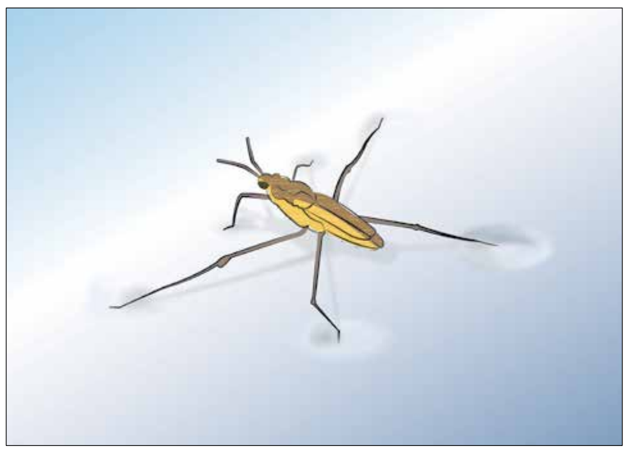

Figure 15. Insect supported on the surface of water.

The first question we should ask our students refers to the mechanism by which the insect stays on the surface. Most of them will suggest that the insect is floating, since the model they have of things that do not sink when they are at the surface of a liquid is that of flotation (indeed, they have no other concept to explain this. For this reason, our first task is to destroy the false concept that everything that does not sink must be floating.

To do this we must go back to experimentation and put objects of greater density than the water on its surface, as well as others that are less dense (Figure 16).

Figure 16. Steel paperclip onto the surface of the water.

Although this operation may seem difficult to us, we can help by using the trick indicated below, where one paperclip is used to slide the other gently onto the surface of the water (Figures 17 and 18):

Objects that float are easy to identify, since if they are pushed under with a finger they return to the surface.

Figure 17. Steel paperclip used as a tool.

Figure 18. We can support the paperclip on the water surface in this way.

In addition, part of the object is below the surface of the water (Figure 19), since the weight of the water of the submerged volume is what makes it float.

Figure 19. Floating object must present a submerged part.

However, objects that do not float, like the insect or the paperclip, have no submerged part, and if they are pushed under with a finger, they do not float up again (Figure 20).

If we extend the analogical model we used to represent a drop of water with a full balloon (see previous Figure 14), the water surface in the glass will behave in the same way as the rubber of a balloon, resisting being broken by the weight of the insect just as a trampoline holds the weight of a person, with a small deformation, like that seen on the surface of the water (Figure 21).

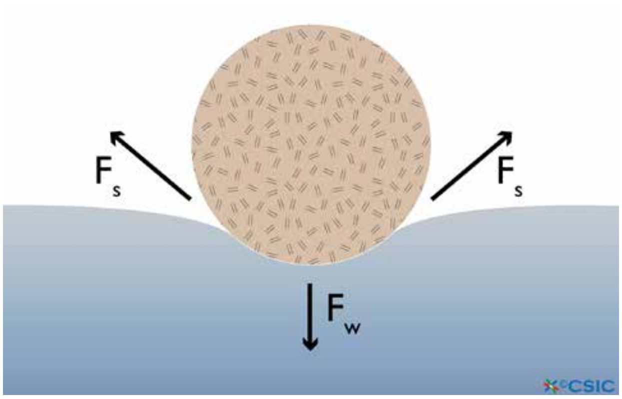

Figure 20. An object supported by surface tension.

Therefore, the elastic, sticky skin model, constructed specifically to explain the formation of drops has passed its first test.

But a representation, in the Piaget sense, or a scientific model, is always subject to a cycle of assimilation by means of constant confrontation with new observations and experimental results from the outside world[2].

1.4. DESCRIPTION OF THE WATER MODEL: KNOWLEDGE AND COMPETENCE

The students will have to be able to describe the model constructed to represent the processes of cohesion and adhesion in the case of water. It should be clear that the description of the *model summarises the knowledge acquired,* which is complemented by *competence, in other*

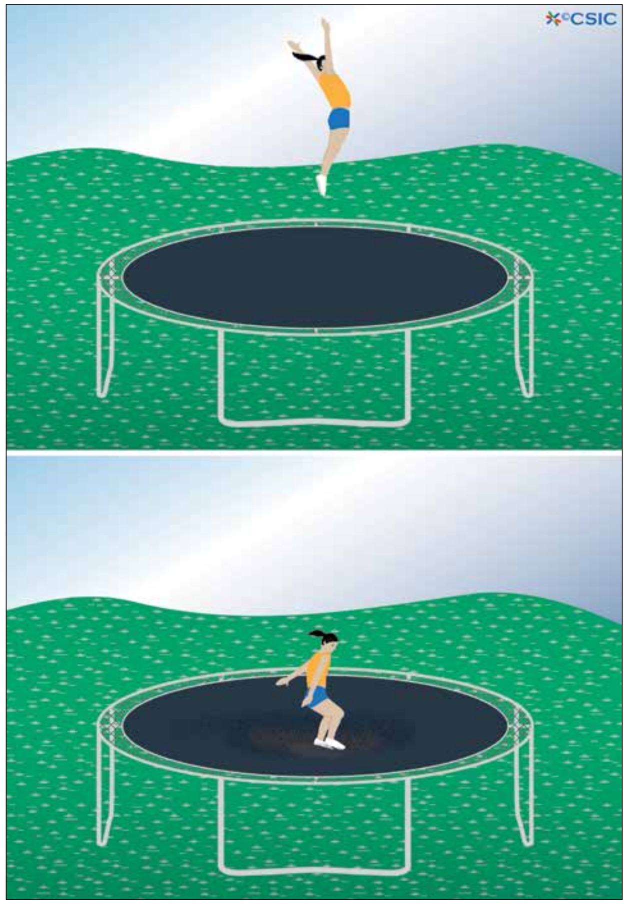

Figure 21. Skin analogic model of water surface tension.

words, their capacity to apply this model to solve new problems.

The surface of any portion of water behaves as if it were an elastic layer, with adherent properties that depend on the materials with which it is in contact.

The existence of that *skin* allows small insects and light objects to be held on top of the water, even though their density is greater than that of the liquid.

The elasticity of the surface layer is responsible for the cohesion of water; and its capacity to stick to other substances produces the adhesion itself.

[2] Piaget, J., 1929. *The child's conception of the world*. New Jersey: Littlefield, Adams.

The force necessary to break the surface layer is a measurement of the water's elasticity, and we call this *surface tension*.

Remember that we have taken water as a *case study* to represent all substances. For this reason, *in principle*, we will extend the model to all liquids, always with the corresponding verification through experimentation.

Acquiring the necessary competence in the use of our model

The next experiment we will propose in our classrooms, is that of the wet finger (Figure 22), where we ask our students to explain how the column of liquid forms, using the new concepts we have introduced. It is easy to see that the downward vertical force exerted by the paperclip has been replaced by an upward vertical force caused by the water adhering to the skin of the finger. In this way we can check whether our students have acquired the necessary competence to use the model for problem solving.

The following experiment allows us to semi-quantitatively estimate the value of the adhesive forces. It consists of taking a coin, cleaning it carefully with soap, and rinsing it with water.

Figure 22. Upward vertical force.

After drying it, using a set of equivalent droppers, our students have to count the number of drops that can be placed onto the coin without the water spilling off and wetting the table. Most importantly, they must also explain the experiment (in such a way that anyone who reads their description could reproduce it), and carefully record the number of drops (Figure 23).

The result, before the water spills off, is truly spectacular (Figure 24).

Figure 23. Drops on a coin.

Figure 24. Amazing result of the experiment.

The students have to explain what happens so that such an exaggerated meniscus forms without the water spilling off, identifying the forces that appear in the water, as well as between the coin and the water.

As we have mentioned, this experiment produces a quantitative result: The number of drops. For this reason it is time to ask the following question: what does the magnitude of the adhesive force between the water and the material of the coin depend on? The students are likely to reply that it depends on the nature of the surface of the coin. To check this, we can use furniture wax to cover the coin, rubbing it until it shines. After doing this, we can repeat the experiment, record the result, and compare this with the result obtained for the surface of the clean coin, trying to explain the results. Evidently, the *skin* of the water adheres less strongly to the waxed surface than to the surface of the clean coin.

And what would happen if we changed the liquid? Do all liquids have a *skin* with similar characteristics? The only way to discover this is to design an experiment that gives us an answer. The simplest of all consists of using a different liquid, oil, for example, on a clean coin and determining the number of drops necessary for the oil to spill onto the table. We can discuss the results in the class.

There are many easy-to-do and understand experiments that use the concepts we have introduced and the analogical model of liquid we have constructed. Another experiment we can carry out in class involves balancing a credit card on the edge of a full glass of water, a square one if possible, so that the inner part of the card touches the surface of the liquid (Figure 25).

Next, they add small counters to the outer part of the card until contact is broken with the water, recording the number of small counters needed as a measurement of the adhesive force between the liquid and the plastic card. Although the method is far from being precise (as the counters are not always placed at the same distance from the edge of the glass, the card may be imprecisely positioned, etc.), the experiment constitutes a very good first contact with conceptualising the process of measuring, particularly for younger children. We must pay special attention to the water surface rupturing process, the skin in our analogical model, and (if possible) even obtain a slow-motion video where the elasticity of the liquid surface can be observed.

Figure 25. Adhesion forces at work.

The spectacular nature of these experiments may lead some of our students to think that the skin we have introduced to describe a drop, or the surface of the water in the glass, is real. We can demonstrate that this idea is false by telling them to try and find the *skin* by moving a small stick through the surface. In this way they conclude that *the surface layer of the water behaves as an elastic, sticky skin*, but that it is, in fact, only water.

1.5. THE STEP FROM A CONCEPT TO A MAGNITUDE: MEASUREMENTS

We will start this section by defining what a magnitude is, using the most basic definition we know: *magnitude is the name given to everything that can be measured, weighed, or counted*. The price of fruit, the height and weight of a person, and so on, are magnitudes. And if we think about it more deeply, we can conclude that the elasticity of the skin of a balloon also is a magnitude, because it is something we can measure. For our purposes, it is enough to determine the elastic limit or force necessary to burst it. To do this, we will use a *precision balance*, easy to construct and to use, to approximately determine the value of the water's surface tension (Figure 26).

Figure 26. Our precision balance.

This can be made from a couple of one-litre containers, drinking straws, sewing thread, and a big-headed pin. We also need a bottle top and a glass containing the liquid we want to measure the surface tension of, in this case water. The measurement can be made using drops of water, grains of rice, lentils, or anything similar.

Once we have our balance, we will use a simplified variation of the Du Noüy (1883-1947) method. This consists of hanging a certain length of drinking straw from one of the arms of the balance, as shown in the illustration. In order to equilibrate the balance we have to add a little plasticine to the arm that needs it.

Next, we introduce the straw into the glass of water, so that it stays in contact with the liquid while the arms of the balance are horizontal. The measurement process consists of very slowly adding grains of rice or drops of water until the straw in contact with the surface of the water becomes *detached*. The number of grains of rice or drops of water (which we assume to be proportional to the weight) gives us an idea of the magnitude of the surface tension. If we did this experiment with straws of different lengths, but made of the same material, we would see that the force necessary *to break* the surface tension is proportional to the perimeter, in other words, approximately double the length. This is logical, since the *skin* that breaks corresponds to that which forms along the two sides of the straw.

We could also use a 5x5 cm square of glass or a Compact Disc to which we attach a handle using epoxy glue. If we spread water over the surface of a table and press our piece of glass/ CD onto it, we can see that the cohesion forces stick them firmly together, in such a way that we need a dynanometer to determine the force necessary to detach them (Figures 27 and 28).

Figure 27. Adhesion forces between CD and the table.

In the case of using a 5 x 5 cm square glass ring, the surface tension measurement, in newtons per metre (N/m), is the result of dividing the force indicated by the dynamometer at the moment the glass detaches by the double of the perimeter of the square, in this case 40 centimetres (Figure 28).

Figure 28. Measuring adhesion forces.

1.6. LIMITATIONS OF THE *SKIN* MODEL

The analogical model we have constructed is appropriate for describing the macroscopic properties (mechanical behaviour) of water. It is based on the particular behaviour of the surface layer of water, which immediately raises the following question, suggested by the properties of the model:

¿*Why* does the surface of any portion of water behave as if it were an elastic layer, with adherent properties?

Our students have to realise that the explanation for the behaviour of the outer layer of liquids should be looked for, or invented, beyond the model, as this cannot account for its own behaviour. This is the way scientific knowledge is constructed, like the layers of an onion, where the innermost ones provide a reason for the behaviour of the outer ones.

In order to investigate the composition of water, we must focus on the processes where it is subjected to the most severe changes, such as changes of state. In these processes, the properties and appearance of water change, but it continues to be water, and our students must comprehend evaporation and condensation, fusion and solidification.

To start with, it is enough to observe the process that takes place when you hang wet clothes out, where very quickly they become completely dry. Where has the water gone and in what form? (Figure 29).

Figure 29. Evaporation process in hanging clothes.

This is a very good question to discuss in a class, making sure you note down the students' answers. At the same time it allows us to show our abilities to direct the discussion using the Socratic method, which will lead us to the conclusion that the water has moved, necessarily, from the fabric into the air, in a form which is invisible to our eyes.

The first thing we must check is that the water really is in the air. To do this, we have to create an experiment to recover it and return it to its liquid state, in other words, condense it. After a small class discussion, we will need to get a soft drinks can at a sufficiently low temperature (lower than the dew point), dry its surface with a napkin, place it on an equally dry paper plate and closely observe what happens. Before our eyes, drops of water will begin to form on the surface of the can, in an inverse process to that which took place when the clothes were drying (Figure 30).

Figure 30. Small water drops condensing on the surface of a cold can.

We can do both experiments simultaneously. It is absolutely certain that the water is in the air in a form we cannot see, but we can still manipulate it. This will be, for some of our students, the first time they come up against a world that exists beyond the reach of their senses. Now you should open their eyes and explain to them that we cannot see the huge majority of the world that exists, but we can imagine it, and even manipulate it.

It is easy to arrive at one *hypothesis:* because the water is in the atmosphere and we cannot see it, the particles must be in a sufficiently small form that they are invisible to our eyes. However, in addition, they must still be water, because we can turn them back into their liquid form just by cooling them. In line with previous research that has been done by other people on this subject, we will call these particles *molecules*. This mental representation of water made up of molecules is known as the molecular model, and it needs to be equipped with laws that describe the behaviour of these molecules, in order to become a theory (theory = model + laws).

The difference between a theory and a model is by no means as clear as can be understood from the works of science philosophers or teaching specialists. In fact, scientists are not accustomed to distinguishing between the two terms, because when these terms crop up, they do so in a specific context where the model or theory is well-known, without apparent ambiguity. In contrast, it is only when we talk about a model or theory in an abstract way that the question of the identity of one concept or the other arises. Along these lines, we can mention a Wikipedia article on the standard model: *The Standard Model of particle physics is a theory* concerning weak, and strong electromagnetic interactions, as well as classifying all the elementary particles known.

We can say that every model contains some characteristics of theory, and all theories can be complemented by a model. For this reason, and particularly at the level we are dealing with, we can continue to utilise the most widely used term in each case, as long as it is clear which model or theory we are talking about.

At this point, we must bring the two models together. On the one side is the elastic behaviour of the surface of water; and on the other is the molecular model. A series of forces must act between these molecules that explain the appearance of cohesion, adhesion, surface tension, and so on, whose characteristics we can intuit, but whose nature we must discover. They must also explain the changes of state, for which they were created.

In principle, we can model molecules as small, spherical balls (Figure 31). In this way we can describe the molecular hypothesis using a simple model that, of course, we will have to test (against facts and experimental results). So, let’s see if the molecular model hypothesis allows us to explain the existence of the three states, as well as the cohesive and adhesive forces.

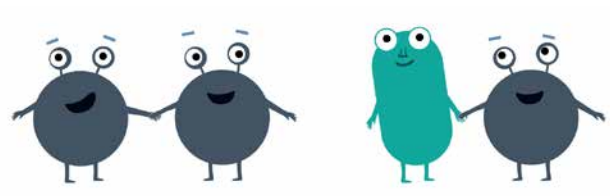

Figure 31. Toy model of cohesion (left) and adhesion (right).

In the molecular model, gas is made up of molecules that move quickly and *which must bounce elastically* when they hit the walls of the container they are in. As we mentioned before, when we associate behaviour governed by laws to the molecules in the model, we are constructing a theory.

When two molecules hit one another, the shock must also be elastic, because if not, in time the gases would become liquids, as the molecules would slow down. So the molecular theory explains that a gas completely occupies the volume that it is contained within.

It is also easy to imagine the liquid state using this model. Liquid water is made up of molecules that are in contact with each other, but can "rol" on top of others. We can analogically model this by filling a glass with marbles. Their volume is constant and fits to the shape of any container, just as a liquid would.

We can also understand the solid state using this model. The molecules in ice are solidly joined to each other, so that both the shape and the volume is conserved.

Once the molecular theory of elastic spheres has been selected, we can carry out new experiments with the water and try to explain the results using this theory. These exercises belong to the Piagetian cycle of assimilation[3].

1.7. CONSIDERATIONS ON HYPOTHESES, MODELS AND THEORIES

If we reflect on the mental pathway traversed, we can see that the hypothesis we have constructed is that water is composed of sub-microscopic particles.

A hypothesis is a creative supposition, developed with the intention of explaining behaviour, deduced through observations and experiments. So the molecular hypothesis, in the case of water, responds to the fact that water vapour and liquid water transform into one another, which forces us to think that they are the same thing. It also explains why in its gaseous state we are unable to see it, yet in its liquid state it is visible. And, finally, it explains

[3] Piaget, J., 1983. Piaget's theory. In: P. Mussen, ed. *Handbook of Child Psychology*. 4th edition, Vol. 1. New York: Wiley.

the greater density of the liquid compared to the gas.

This molecular hypothesis involves a model: that of spherical molecules. We use the name model, at the level we are dealing with, for any *mental representation of a physical system where we describe the composition using icons or symbols*.

When the elements of the model obey the laws of a discipline, we have formed a theory. Thus, *the molecular theory of matter is formed by associating the molecular model of spherical molecules with the behaviour of these, according to the laws of classical mechanics*.

1.8. THE NATURE OF INTERMOLECULAR FORCES

If we extend the molecular theory our case study, it is evident that the phenomenon of cohesion must originate in the forces between water molecules, and the adhesion phenomenon must involve forces of attraction between the water molecules and molecules in the solids it is in contact with (Figures 31 and 32).

Figure 32. Cohesion between water molecules; adhesion between the molecules in water and the coin.

We can change the spherical molecule model that we have suggested for an analogical model of the students themselves. In this case the cohesive forces are those that hold some molecules to others, whereas adhesive forces are those that appear between the table on which they are climbed (which represents the coin) and the students, exerted by the friction of the soles of their shoes (Figure 33).

Figure 33. Dramatization of cohesion and adhesion forces on a coin.

This is a model that everyone can understand very easily, as we can see from the descriptions the students generate using the corresponding symbols.

As we can see, the model we use is not particularly important. The important thing is to understand what the representation means.

The fact of furnishing the molecular model with intermolecular forces requires reflection. These forces should be of some known and studied type, so that we can apply the corresponding laws to the elements of the model, in other words, to the molecules. At this level and at this scale, we know of three fundamental forces: gravity, magnetism, and electricity. We can now review these interactions to find out which is responsible for the cohesion and adhesion.

The gravitational force requires large masses in order to be effective. This is the case of the attraction between the sun and the planets, or between galaxies. It is evident that gravity cannot be responsible for the intermolecular forces, since their masses are tiny. Magnetic or electrical forces could originate the cohesion and adhesion, as they are sufficiently strong to explain these phenomena. We must therefore design an experiment that helps us discern which of them it is.

If the force between molecules is magnetism, the water molecules must have some type of magnetic dipole and be sensitive to the field of a powerful magnet. To determine whether this is the case we can bring a neodymium magnet close to a very fine stream of water from a tap that is running very slowly (Figure 34).

Figure 34. Water is not magnetic.

The result will be, as all we know, negative. Even though the magnet is very powerful and the stream of water very narrow, it does not deflect it. In fact, we could have anticipated this result. For the opposite to have been true, we ourselves, being composed of a high percentage of water, would be attracted by magnets, something that does not happen.

We can now test what happens if an electrified balloon approaches the stream of water (Figure 35).

Figure 35. An electrified balloon attracts a narrow stream of water.

This time the result is positive: the electrical charge of the balloon exerts a force of attraction on the water, deflecting the stream. This indicates that the water molecules are polarised by the presence of the balloon or, if they are polar, they orient themselves.

Based on the results of these experiments we can hypothesise that the water molecules have electrical charges and that the forces which appear between them (cohesion), or between the molecules of water and those of other materials (adhesion), are electrical in nature. Let's accept this working hypothesis for the time being.

Once we have decided that electrical forces must be responsible for the intermolecular forces, we need to develop the molecular model for water. However, to do this we must first go deeper into the study of electrostatics, so that we can apply its laws to the possible molecular models that we propose, in our attempt to explain the existence of adhesion and cohesion.

2. SECOND PART: A QUICK LOOK AT THE HISTORY OF ELECTROSTATICS

The history of science, just like any story referring to a specific subject, comprises a series of events that occurred through time, arranged chronologically, as a chronicle. However, for this narrative to be considered a story, it must have a structure or, as suggested by Aristotle, a *plot* involving characters, approach, development with a conflict, and a conclusion or ending.

Chomsky postulated that children are born with a specific capacity that allows them to be *competent* in language, in other words, to be able to understand and emit phrases they have never heard before. In the same way it seems evident[4] that they also have the innate capacity to organise temporal events in the form of stories around a plot, as well as recognise the plot in stories they listen to. In fact, when we tell a child the first part of a story, they immediately understand that the plot has not been completed.

Therefore, the history of science presented to a young audience must employ the Aristotelian structure, so that the children can memorise it helped by its internal structure, which is the same as that of the stories they are accustomed to.

Therefore, a historian hypothesises that later events must in some way be due to what happened earlier, supposing the existence of a logical structure that *tells us* why history happened in one particular way and not another. It is about obtaining patterns of behaviour (laws), for which historians devise concepts that help model history, such as social classes, ideologies, great women and men, the will of the gods, or the fight for survival. The existence of this structure is what makes history a science.

In this quick look at the history of electrostatics we will reduce our story to the points we consider essential, defined by its main figures (treated like *great scientists*), and we will provide the basic coordinates of when and where the events took place. To provide a structure for this narration of facts, we will use Piaget's theory, the only one we know of that explains both the nature of knowledge and the way it is elaborated. This theory has proven to be useful not only at a personal level, but also in the study of knowledge in scientific societies (Kuhn), and artificial intelligence. Obviously, there are other types of structures that can be applied to history and each defines a theory.

2.1. THE BIRTH OF A SCIENCE

Our story begins in the 7th century B.C., the time when electrostatics was first discovered (the main figure in this is Thales of Miletus), and it finishes in the 18th century, almost two and a half millennia later.

Throughout our time at school, we learned about the great thinkers of the classical world as pure philosophers, understanding this word with its modern meaning, when in fact their attitude and work was much more similar to what we now think of as scientists. Although, in reality, these human characteristics and attitudes are inexorably joined, it seems appropriate to us that we should point this out, fundamentally to help to deconstruct the ridiculous antagonism between the arts and sciences that is still found

[4] Chomsky, N., 1990. On the nature, acquisition and use of language. In: W.G. Lycan, ed. 1990. *Mind and Cognition: A Reader*. Cambridge and London: Blackwell. Pp.627-45

in the western world[5].

We can imagine that one day, cleaning a beautiful piece of amber with a cloth, Thales observed that rubbing endowed it with the unusual property of being able to attract small objects, in a similar manner to the way magnetic stone attracts iron objects. Our students should repeat the experiment carried out by Thales, using a drinking straw that they rub with a paper napkin, checking that it attracts small pieces of paper and other tiny objects (Figure 36).

Figure 36. Observing electrostatic forces.

We can give name to this phenomenon, because it corresponds to a concept: *electrification by rubbing*. This allows us to refer to it in a simple, easy way. In addition to amber, this property is displayed by an extensive group of materials that Thales christened *electrifiables*. This clearly implies the existence of another class of materials that cannot be electrified by rubbing, which we will call *non-electrifiable materials*. Among these, the most important group is that comprising metals.

In order to bring our journey through history to life, our students have to carry out directed experiments in order to distinguish the objects belonging to the two groups. To do this, they should rub paper napkins on any kind of material they have at hand, checking whether they acquire this strange ability to attract small objects. The result is very interesting: metals, used in electrical circuits as conductors, cannot be electrified; however, plastics and other materials that we use to insulate electrical cables are easily electrifiable. And we must point out that whenever there is a classification, be this of materials or the behaviour of living beings, we must look for the underlying scientific reason, which will show us which way to go in our research.

2.2. LEUCIPPUS AND THE REASON WHY SCIENCE EXISTS

Leucippus lived about two hundred years after Thales (460-370 B.C.). Probably based on the way Thales presented his results, he established the basic postulates of science, which are still used today. Leucippus was also probably born in Miletus, like Thales, and he was the teacher of Democritus. This fact is important because between the two of them, they came up with the first atomic model (modifications of which we have used to explain the behaviour of water), many years later. In reality, as we can see from numerous examples, the strongest and most persistent things in time are not buildings or monuments, but ideas.

Leucippus was aware that science is a human construct, and he raised the issue of whether people could acquire knowledge of the world through observing natural phenomena, using their senses. And, as children do from the time they are born, he realised that things always happen in the same way, allowing us to make predictions. As he was a Greek from the 5th century B.C., he expressed this fact by saying that the Gods organised the world just as

[5] Snow, C.P., 1956. The Two cultures. *The New Statesman*, [online] 2 Jan 2013. Availible at: <https://www.newstatesman.com/cultural-capital/2013/01/c-p-snow-two-cultures>

governors organise their cities and nations, by means of laws. And he defined the so-called ***laws of nature***, which scientists discover, as statements describing the way nature behaves. This information is obtained through observation and the results of experiments.

As Leucippus did not do any experiments at all in his research (he was a philosopher of science), he formulated his conclusions using *postulates*, truths taken as evident but which are impossible to demonstrate: they are assumed to be true as there is no reason for rejecting them. It is clear that if a single result is found to contradict them, the postulate is no longer valid.

First postulate of Leucippus: this establishes that the *Gods do not play with us to confuse us. For this reason things do not behave in a whimsical manner, but rather follow laws that are always respected*. Bodies, if left in the air, always fall; bubbles in water always rise, and so on. This law could also be explained by saying nothing happens at random and that *the same causes have the same effects*.

In summary: like all the babies, Leucippus reached the conclusion that there are laws of nature, which are fixed and necessarily fulfilled in all cases. Children, from when they are just a few months old, discover that things do not disappear, and it becomes a game to find the objects their mother has hidden under a cloth. Similarly, they are constantly investigating and enthusiastically try to discover how phenomena happen, sure of the fact that they always occur in the same way. Leucippus also talks about this surety in their capacity for discovery.

His second postulate states that people are able to *discover* and set out these laws of nature, although he does not describe the procedure or method that leads us to their discovery. It was not until after the Renaissance that Galileo, Kepler and Bacon would tell us how we could arrive at knowledge of them (the first scientific method).

It is interesting to look a little deeper into the nature of these laws, as Leucippus conceived them, because the meaning he assigned them has lasted until the present time. A law of nature is, as we have said, a description of natural behaviour that we have not demonstrated, but rather deduced from our experience (guessing *generalised behaviour from a few specific observations*). This way of reasoning, through induction, is basic to human nature and can be seen from the first months of our existence. As soon as children observe that objects fall if left suspended in the air, it becomes a game to drop their toys, in the surety that *they will all* behave in the same way. They very quickly understand that magic tricks are extraordinary behaviour, and they make great efforts to discover the trick.

Therefore, from the observation that rubbing amber electrifies it, independently of where the experiment takes place (on land or in the middle of the sea, the mountains, or at the beach) or who carries it out (man, woman or child), *Leucippus deduced* or supposed that this was a general behaviour of nature, in other words, *a law*. But since he had verified this in a ridiculously low number of cases, he could not be sure that, at some time, in some place, this law might not be adhered to. Thus, a law is always a *provisional description* (as we will soon see) of what we believe is general natural behaviour. For this reason we must be willing to replace it with another more general principle. Throughout this story we will see examples that clarify this procedure, which is no more than the Piagetian scheme of knowledge construction.

Another consequence of Leucippus's statements is that the laws of nature contrast with magic, as they do not require secret knowledge sorcery and enchantment. As we can see, Leucippus earned an important position in the history of science —or should we say philosophy?

2.3. THE RENAISSANCE OF THE WESTERN WORLD

For 2200 long years, the history of science was a quiet place where the laws of Thales of Miletus were preserved, unchanged.

But in the 15th century, for various reasons and probably related to the *Renaissance* (of virtues, interests, and heritage from the classical world), society developed a new attitude to knowledge. That attitude would give rise, very soon, to the *scientific revolution*.

In our opinion, one of the causes was the rediscovery of the works of the Greek philosophers by the Arabs. These manuscripts were translated into Arabic and, at the bidding of Alfonso X of Castille, Spain (known as *the Wise*), translated from Arabic into Latin at the School of Translators in Toledo. These translations were copied in countless convents and the copies were distributed throughout Europe using the Camino de Santiago and the *road to Rome*. This meant the rediscovery of the classical world gave rise to the intellectual awakening that was one of the causes of the Renaissance phenomenon. But this is only one theory.

With the discovery of America, science gained a production parameter, in other words, economic importance. We are now in the 16th century. To sail from Europe to America, the ship captains had to understand astronomy and terrestrial magnetism, in order to orient themselves over a 20-day journey. The captain's education was fundamental so that the passage was sufficiently short, and the sailors did not fall ill with scurvy, and neither the boat nor its shipment was lost. For this reason, improvements in the model developed by Copernicus and advances in magnetism were of enormous economic importance. This is the reason William Gilbert (1544-1603) now enters our story. He was the royal physician to Queen Elizabeth I of England, *the Virgin Queen*, after whom the vast North American territory of Virginia was named, and which England annexed.

Gilbert loved physics, and he used to demonstrate to the Queen, with whom he probably attended Shakespeare premieres, magnetism and electricity experiments, using the term *electricus*, to describe the strange fluid responsible for the electrical phenomena. Since electricity and magnetism were very similar phenomena, Gilbert studied both at the same time.

As we have mentioned, the knowledge Thales of Miletus had relating to electricity arrived at William Gilbert almost unchanged.

- First law of Thales: when a body is rubbed (i.e., electrified), it attracts small objects near to it. This property is lost through time.

- Second law of Thales: There are bodies that can be electrified by rubbing and bodies that cannot (electrifiable and non-electrifiable).

Around 1600, Gilbert wrote a treatise in which he explained the difference between magnetism and electricity, a difference that can be tested using a simple instrument he invented, called the *versorium*. We can build one easily in the classroom, by simply suspending an elongated piece of aluminium foil (preferably the kind used in the oven, because the foil is thicker) by its centre of gravity (Figure 37).

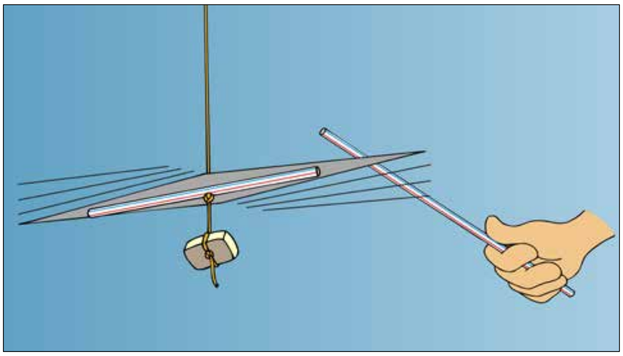

Figure 37. We can make a *versorium* using simple materials.

The description of how it works, at the historical moment in which we find ourselves, is this: a rubbed body (charged, as we would say today) attracts any neutral body (electrifiable or not) that is close to it, in agreement with the law of Thales. However, a magnet only attracts objects made of magnetic materials (at that time, only iron and some of its minerals were known). And Gilbert, in the middle of a historical period that wanted to demonstrate how important the heritage from the classical world was, christened this new discipline *electricity*, a derivative of the Greek name for amber, *elektron*. The words electricity and electronics derive from this term.

Despite of the simplicity of the laws of Thales, they led towards a practical application. Throughout the Middle Ages it was normal to see spinners using a spindle whose bottom part was finished in an amber piece they rubbed against their skirt while they spun. This electrified it and they were able to use it to pick up the thread off the ground, without bending down, when it accidentally broke.

2.4. FRANCIS BACON INVENTS A METHOD FOR DOING SCIENCE: IF WE FOLLOW THIS, WHAT WE OBTAIN IS GUARANTEED TO BE *THE TRUTH*

Another influential personage of that time was Francis Bacon, Baron of Verulam (1561-1626), who added a new postulate to those proposed by Leucippus two thousand years earlier.

In 1620, he published his work *Novum Organum, or True Suggestions for the Interpretation of Nature*, where he described the experimental method to be applied to the sciences, contrasting it with the Organon of Aristotle (only good for discussions between colleagues). In this way, Bacon added a new postulate to those of Leucippus, in which he explained the procedure for discovering the laws that govern the world.

New postulate of Bacon: *If you want to know how nature behaves, the only way is to ask it directly*, by means of well-designed experiments.

In other words, only nature can tell you how it behaves.

This completements the postulates of Leucippus, which told us there were laws we could find out, but did not indicate the method we should use to discover them.

And this principle, together with the two of Leucippus, formed the basis of scientific knowledge in the 17th century.

Next, we will take a short cut in our story, and jump directly to the new representation we are seeking. This is the advantage of telling a story, it is a virtual space that only exists in our mind and it allows us to move forwards and backwards, and stop at any place or time. This is one of our most useful learning tools.

This path has four important crossroads:

- The first one, in 1629, is the experiment by Cabeo.
- The second knot, in 1725, represents the discoveries made by Gray and Desaguliers, almost a century later.
- The third one is the work of Dufay, in 1733.
- And the fourth knot corresponds to Benjamin Franklin, who proposed the law of conservation of charge, in 1747.

First knot. Discovery of repulsion forces

Some years after the death of Gilbert, in 1620, the Italian Jesuit Niccolò Cabeo (1586-1650) carried out electrostatic experiments using all type of materials. He noted that neutral objects of electrifiable material were attracted by amber and remained stuck to it (following the behaviour described by the laws of Thales), but small metallic objects behaved completely differently. After being attracted by the amber, once they made contact with it, they were violently repelled. In this way, Cabeo discovered the *existence of repulsive electrical forces*, not contemplated in the laws of Thales of Miletus, which had been in use for two thousand two hundred years.

We can reproduce this in the classroom, using tiny pieces of aluminium foil; when approaching a rubbed PVC bar we can see they are first attracted and then, as they come into contact with the bar, repelled. We can also do a more spectacular experiment using a small ball of aluminium foil or a paperclip suspended using a thread. When approaching the electrified bar we can see the initial attraction and subsequent repulsion (Figure 38).

Cabeo's experiment should be reproduced by each student, and described and represented in their notebooks. These annotations will be useful when, shortly, the history of science will

Figure 38. Electrified PVC bar attracting little aluminium pieces.

take us to a place where we can explain what happens with an appropriate model that Cabeo did not know about. In this way, they will realise what scientific advances and discoveries actually represent. Historically, the process took about forty years, but for our students it will be just a few days.

Second knot. The discoveries of Gray and Desaguliers

All materials can be electrified

The following discovery, which contradicts the laws of Thales, was made by Stephen Gray (1666-1736). Gray was born in the year of the Great Fire of London (which coincided with the end of the *Great Plague*), and he had the misfortune to place himself scientifically on the other side of the fence to Newton. In 1727, Gray posed the question of why metallic materials were repelled by an electrified bar, after touching it, unlike non-metals. Intrigued by the strange behaviour of these materials when faced with electricity, as discovered by Cabeo, Gray devised and carried out many experiments. He discovered that *metals can also be electrified*, when they are isolated from the experimenter's hand with an electrifiable material.

We can reproduce the Gray's experiment in the classroom using a copper tube with a handle made of PVC or any other plastic. We will see that when we rub the copper tube with a fabric, preferably waterproofed with teflon (used in the treatment of certain table cloth, for example) the copper tube is electrified, just like the PVC bar.

Therefore the distinction between electrifiable and non-electrifiable materials disappears, and a new second law can replace the old one:

Second law of Thales: There are bodies that can be electrified by rubbing and bodies that cannot (electrifiable and non-electrifiable)

New Second law (of Gray): *All materials can be electrified by rubbing*.

But Gray continued to look for differences between the two previous classes of materials, convinced that the strange behaviour of metals (which do not become electrified when held) must be due to some yet unknown property.

Metals conduct electricity but insulators do not

Two years later, working with his friend and protector Jean Theophile Desaguliers (1683-1744), Gray discovered the hidden property that distinguishes metals from non-metals: metals conduct electricity, allowing this to move from one point to another in the metallic object.

It is easy to reproduce Gray and Desaguliers's experiment in the classroom. To do so, we have to place a copper pipe on a plastic glass, with a small ball of aluminium foil or a paperclip suspended on a thread very close to one end of the pipe. At the moment an electrified bar of PVC touches the other end of the copper pipe from the paperclip, the pipe attracts the clip.

This proves that the charge from the PVC bar is transmitted to the end of the metal tube and this attracts the paperclip through induction: the metal is a conductor.

In this way, the two researchers established a new classification of materials: *electrical conductors* (corresponding to what Thales considered non-electrifiable); and non-conductors, known as *insulators* (corresponding with the electrifiable materials of Thales).

The human body conducts electricity

Gray and Desaguliers continued to experiment with the materials they had around them, to verify the law they had just discovered. Among other tests, they tried to electrify their fingers by rubbing them with fabric, wool, skin, and so on, to see if they could attract fragments of paper. They reached the conclusion that fingers could not be electrified by rubbing. They assumed, correctly, that the same happened to the human body as to the copper pipe, it was a conductor, and therefore the charge generated by rubbing was distributed throughout the body and passed into the Earth through the feet or the footwear. In order to verify this, they insulated a person by suspending them with ropes of very dry silk. They then connected the person to an electrostatic machine and checked that the human body remained charged, and maintained this charge in the same way as any other object (Figure 39).

In this way they discovered the human body is a conductor, even though it is not metallic. This revealed another mystery to be investigated: the nature of non-metal conductive bodies.

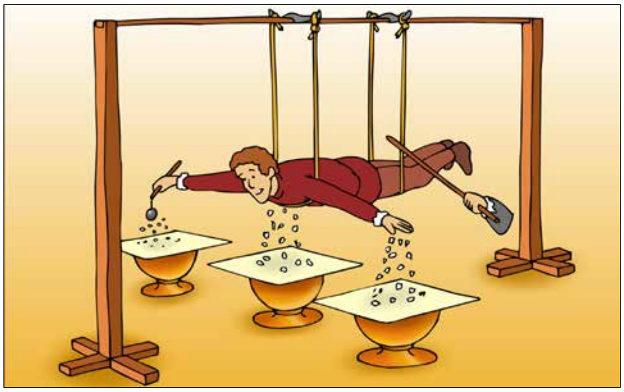

Figure 39. An electrified young man.

These new discoveries made it possible to understand why Thales could not electrify a metal when he was holding it in his hands. Even though a lot of electricity was generated by rubbing, this was conducted to the human body, from where it was diverted into the Earth through the shoes. Once this was understood, the idea spread to the fairs in the form of the *electrical kiss*: a young girl was insulated using silk cords and charged with electricity as described. When she kissed a non-insulated person, part of the electrical charge passed to the Earth through their body, producing the characteristic sensation of *electric shock*[6] (Figure 40).

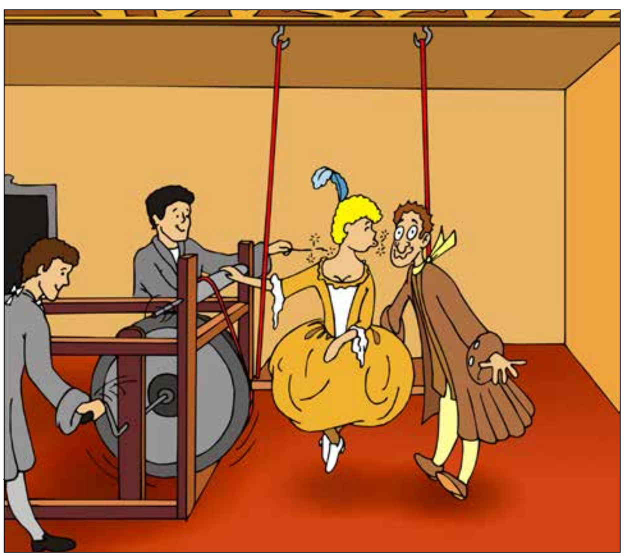

Figure 40. The *electrical kiss*.

Third knot. Thanks to Dufay

There are two classes of electricity

In 1733, only four years after Gray's discoveries, Charles François Du Fay or Dufay (1698-1739) made a finding that was crucial for the development of electrostatics: the existence of two types of electricity, which he called vitreous and resinous, as they were obtained either rubbing a piece of glass with a silk cloth (which in modern convention acquires a positive charge) or a piece of amber or any type of resinous substance (which acquires a negative charge).

It is very easy to repeat some of Dufay's experiments in the classroom, using very simple materials. Let us begin by joining two differently coloured drinking straws (orange and yellow at the image under these lines -Figure 36-) and suspending them by their join so that they are balanced (Figure 41).

Figure 41. The Dufay experiment in the classroom.

In the first part of the experiment we rub the yellow (at our example) straw with a paper napkin, having taken care not to touch the part of the napkin that has been in contact with the straw with our hands (Figure 42). If we bring this part of the napkin close to the yellow straw we can see that the two elements are attracted (Figure 43).

Figures 42 and 43.

The second part of the experiment consists of rubbing another yellow straw (out of the two joined and suspended ones) with a new napkin. It is easy to check that as the two yellow straws get close to each other they are repelled (Figure 44).

Dufay, whose research was motivated by the works of Gray and Desaguliers, interpreted the results of this experiment (and other similar ones) assuming that when the plastic straw is rubbed with the paper napkin, the plastic acquires a negative charge and the paper a positive one. Immediately, the researcher deduced what was happening, and he synthesised this in what we can call the **law of Dufay: charges of the same name or sign are repelled, while those of different signs are attracted**.

The tribology series

After carrying out a huge number of tests, he reached the conclusion that there is a natural tendency to electrify when two electrically neutral

Figure 44.

bodies rub together (equal quantities of positive and negative charges). Both become charged, one positively and one negatively. By studying the type and quantity of charge they acquire when rubbed, he drew up an ordered, empirical list of materials known as *the triboelectric series* or *table*, in other words, this was based solely on experimental results (Figure 45).

+ GREATER POSITIVE CHARGE
Human skin
Glass
Nylon
Wool
Silk
Paper
Cotton
Rubber
Polyethylene
PVC
Teflon
Silicone
- GREATER NEGATIVE CHARGE

Figure 45. Triboelectric serie.

The order of the table is such that when two materials of the series are rubbed together, the one closest to the top of the list acquires a positive charge and the other a negative. In addition, the quantity of charge they acquire through the rubbing process is proportional to the distance (in position) that separates the two materials in the table. Therefore, if a glass bottle is rubbed with a cotton cloth a negative charge passes from the glass to the cotton, leaving the bottle positively charged while the cloth becomes negatively charged. We must take into account the fact that the position a material occupies in the series does not depend solely on its composition but also on its surface characteristics (polished, scratched, etc.).

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The experiments we have proposed for the classroom use paper napkins and drinking straws (PVC). As can be deduced from the table, the plastic acquires a negative charge and the paper a positive one (Figure 46).

Fourth knot. Benjamin Franklin's conservation of charge

An important piece of the puzzle was still missing in the field of electricity in order for it to be a complete body of knowledge, and this piece was provided by Benjamin Franklin (1706-

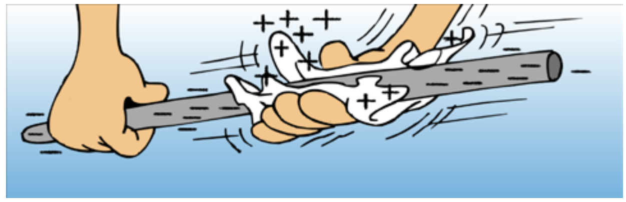


Figure 46. Electrifying a non-conducting object.

1790). In a letter to his friend Cadwallader Colder, a scientist and politician like him, in June 1747, he explains that electricity is not created by friction, but is an element, like hydrogen or oxygen, that exists in nature and is neither created nor destroyed, but rather transferred from one body to another.

These days, Franklin's model of a unique electrical fluid has been abandoned as being incorrect, and has been replaced by the two-charge model, which is what we use in our descriptions. In modern parlance, we can say that there are two electrical charges, those originally discovered by Dufay (positive and negative), and that these exist in exactly the same quantities in neutral bodies. In addition, when rubbing two non-electrified materials together, both charges are redistributed, passing from one body to the other, leaving one with a positive charge and the other with a negative charge.

The law of Conservation of Charge is impossible to verify in the classroom, as we cannot make quantitative measurements. Like all the laws of conservation, it stems from a symmetry[7]. In this case, of gauge transformation; through the theorem of Amalie Emmy Noether (1882 - 1935) this invariance implies the conservation of charge. But at the level necessary for this explanation we can take it as a postulate, deduced from the observation that when we rub

[7] In this case, of the gauge theory; by the theorem of Amalie Emmy Noether (1882 - 1935) this invariance implies the conservation of charge.

two neutral bodies together, the charges they acquire are always of opposing signs, and it is logical to suppose that added together they still equal zero.

Franklin postulated his law of conservation of charge one hundred and thirty-four years after Cabeo's experiment, and two thousand three hundred years after the work of Thales.

2.5. ELECTRICITY IN THE MID-18TH CENTURY

By 1750, new laws of electricity had been promulgated which, stated in modern language, are:

- **Law 1**: There are two types of electrical charges, positive and negative. The world contains the same quantities of each of charges.
- **Law 2**: Electrical charges are neither created nor destroyed. They only pass from one body to another through contact or rubbing.
- **Law 3**: All materials can be electrified by rubbing. The sign of the charges acquired by the two materials that come into contact is that indicated in the triboelectric table, empirically determined through experiments, without laws they must obey or theory to support them.
- **Law 4**: There are materials that conduct electricity (conductors) and others that do not (insulators).

With the discovery of conductors and insulators, appeared the theory of circuits, but for this we have to wait for the birth of Georg Simon Ohm (1789-1854), the same year the French Revolution started. This theory, propounded in 1827, states Ohm's famous law relating voltage, resistance, and intensity. From this comes the transport of electricity, the telephone, electronics, computers, telephones, and an endless list of innovations we are still adding to. But that is another story.

With these four laws, which are science's response to the new discoveries (once it had been demonstrated that they could not be explained by previous laws), *it is possible to explain*, as we will see, *all the electrical phenomena known in the mid-18th century*, christened the Century of Light. From among these we have chosen a particularly relevant example due to its application to intermolecular forces, the beginning start of our story.

A. Polarisation by induction

The fact that any insulating body (like a PVC bar) charged by rubbing attracts neutral insulating or metallic objects, is due to a phenomenon known as polarisation by induction.

The mechanism of polarisation by induction was initially not very clear and would not be understood until a polar or polarisable molecule model was invented. For that reason, in 1750, it was assumed that within these small objects the charges of both signs were separated to a certain extent. If we bring a negatively charged PVC bar close to some confetti, the positive charges in the confetti (attracted by the bar) go towards the surface nearest the PVC and the negative charges (repelled by the negative charge of the PVC) will position themselves at the farthest surface from the bar, producing a charge separation that polarises the confetti. As confetti is not a conductor, it cannot pass charge to the bar and charge it negatively, for which reason it remains stuck to the PVC while the bar remains electrified. But it is also certain that, as confetti is not a conductor, it is difficult to explain how the charges in its interior move apart from one another. This is one of the unanswered questions which marked the direction of the new research at this time. To help assimilate these laws, we propose a series of simple experiments, so that our students realise, in as much depth as their age permits, how the laws are applied to explain the behaviour of nature.

B. Why does an electrified bar attract a neutral conductive body?

The PVC bar is negatively charged when it is rubbed with paper (see previous Triboelectric serie).

- As the metal of a can is a conductor, the negative charges of the PVC repel the negative charges of the container, which move towards the farthest part of the bar (Figure 47).
- When an object has separate positive and negative charges, positive at one end or pole, and negative at the other end or pole, we can say the object is electrically polarised (in this case, by induction).
- As the part of the container nearest the PVC bar is positive, it is attracted by the bar, moving towards it.
- The negative charges of the container are further away than the positive ones, so the repulsion they feel with the bar is less than the attraction the positive part feels.
- When the container turns, the positive and negative charges move within it, so it remains polarised in the horizontal plane.

In this way we have *explained* the result of our experiment by applying the laws of electrostatics.

Figure 47. Can is attracted by the bar

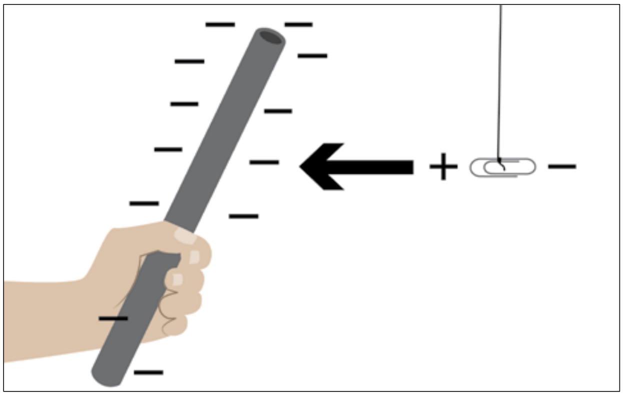
C. Analysis of Cabeo's experiment with the help of the laws of electrostatics

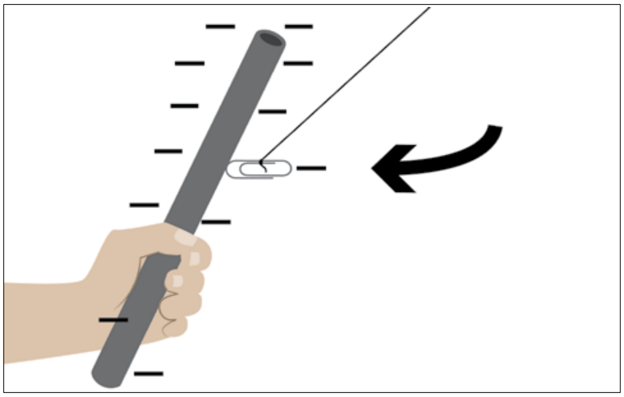
The repulsive electrical force that Cabeo discovered —and which brought an end to the single electrical charge model— can also be explained using Dufay's discovery of charges (+ and -), the movement of charges within a conductor, and Franklin's principle of the conservation of charge. Let's have a look how.

If we rub a PVC bar with a paper napkin, the bar will become negatively charged and the napkin —due to Franklin's law of conservation— will have an equal amount of positive charge.

When a small object of conductive material approaches the PVC bar, such as a paperclip, it becomes polarised by induction in the same way as the can did: the negative charges (which we currently know are mobile in metals) *will escape* towards the far end, leaving the near end positively charged: the metal that is polarised in this way is then attracted by the negative bar (Figure 48).

As a result, the object approaches until it makes contact with the bar and acquires part of its negative charge, since it is a conductor (Figure 49).





Figures 48 and 49.

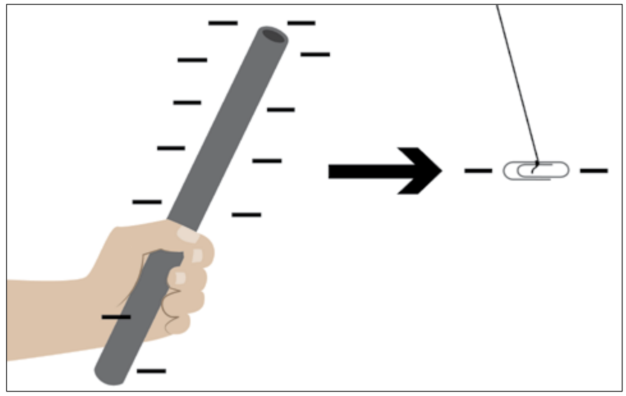


Figure 50.

- When the pendulum, polarised but neutral, comes into contact with the negative PVC, part of the charge from the PVC is transferred to the pendulum, charging it negatively.

- As a result, there is a repulsive force that pushes the pendulum away from the negative PVC (Figure 50).

At the end of the experiment, both bodies are negatively charged, producing the repulsion force that surprised Cabeo so much. From it being impossible to explain using the single-charge model, this experiment revolutionised electrostatics, forcing it to come up with new models that explained this result.

3. THIRD PART: ELECTRICAL CHARACTERISTICS OF THE INTERMOLECULAR FORCES

Now we arrive at the third part of our story. In this part we will try to explain the forces discovered in the first section using the knowledge of electrostatics we have presented in the second section.

Basically, we first described the behaviour of water in contact with solids using concepts based on the forces of cohesion and adhesion. Later, based on the processes of evaporation and condensation, we were able to postulate the existence of the water molecule, and the fact that this is present both in the liquid and gaseous states. In addition, as water is attracted by an electrified body and not a magnet, we supposed that the phenomena affecting the behaviour of water had to be electrical in nature. This conclusion seemed a good working hypothesis, and the reason we then looked at electrostatics, a branch of science that was developed independently from the interactions between liquids and solids.

From a teaching perspective, we now have the problem of introducing the (polar) water molecule in a way that is reasonable and permissible for the students, without having to resort to its atomic composition. This avoids the long path to the atomic model (with the complexities of the periodic table), and the formation of molecules with their stoichiometry and the atomic properties that explain the electrical characteristics of the water molecule.

Our proposal is to do web-based research to obtain information about possible water molecule models (proposed by other researchers), and use these to explain the cohesion and adhesion forces. We just have to type the words *water molecule* into a search engine, choose the *images* tab and check the results.

As we can see, all the images that appear are representations of the same idea: the famous and ubiquitous H_2O molecule, formed by two hydrogen atoms with positive electrical charges bonded to a single, negatively-charged oxygen atom.

This is a good time to reflect on the nature of scientific models, the reasons why they are developed, and their function in scientific research. A model is an iconic or symbolic representation of part of reality, created to explicitly indicate a certain characteristic of that part of reality which is fundamental in the study being undertaken. A map of a city is a good example of a model, as are small-scale reproductions of cars, trains, and so on.

In the case we are dealing with, as we suspect that the forces of cohesion and adhesion are electrical in nature, we should chose a water molecule model where the charges and their distribution are explicitly represented. From this model we will try to understand the forces we have discovered and that we are investigating.

Any model will work if it has these characteristics; we even can use appropriately labelled students (caps showing O- to represent oxygen, their arms extended and holding a poster with H+ in each hand), as long as the representation of the molecule shows the state of electrical polarisation (Figure 51).

Figure 51. Polarisation of water: a dramatization.

With any of these water molecule models, the appearance of attractive forces between the negative oxygen atom of a molecule and a positive hydrogen of any other molecule that is close to the first one can be easily understood. Indeed, if by chance the oxygens of two nearby molecules come close to one another, there will be a repulsive force that will prevent this situation. These forces of attraction between molecules are known as hydrogen bonds, a type of force introduced by Johannes D. Van der Waals (1837-1923) in 1873. For this reason they are called *Van der Waals forces*.

We must realise that, with the introduction of the polar water molecule we have changed the model, from a simple descriptive model to another type that provides us with an explanation of the forces based on the laws of electricity.

When the laws of a consolidated discipline (such as electricity) can be applied to a model to explain observed facts, we say that we have developed a theory.

With this representation it is easy to identify the hydrogen bonds as the cause of the cohesive forces, a macroscopic effect of the (sub-microscopic) polarity of the molecules.

A model is the more useful the more phenomena it explains. For this reason, we will next try to use the same molecule model to understand the forces of adhesion, assuming that their nature is also electrical.

We will begin with the simplest case, in which the molecule is in contact with a non-conducting surface comprising non-polar molecules, for example oiled or waxed paper. As we saw in the first section, and we can remind ourselves by reviewing our notes, a drop of water does not adhere to the oiled paper. This is due to the fact that between the water and oil there are no adhesive forces; this also explains why the two liquids do not mix (and separate due to their different densities). Using our model, we can come to the conclusion that the charged parts of water molecules do not find opposite charges to be attracted to in the surface of the oiled paper. As a consequence, the adhesive forces are null. Teflon is a surface of this type, and it is used widely in waterproof fabrics.

The second case involves surfaces of materials whose molecules are polar, like glass (formed by silicon dioxide). Oxygen atoms have a very high affinity for electrons —almost three times greater than that of silicon— so we can model the surface of the glass as being very polar, formed by positive silicon atoms and negative oxygens. Therefore, water molecules, which are also polar, will form strong bonds with the positive and negative charges on the surface, resulting in important adhesive forces. These forces are responsible for capillary rise in tubes.

Finally, we will study adhesion forces to a metallic surface, such as a sheet of aluminium foil (like that used in the initial experiments that helped us conceptualise these forces). In order to study what happens when a water molecule comes into contact with the aluminium surface, we will represent both elements in a simple diagram.

As a negatively charged oxygen approaches the aluminium, the mobile negative charges of the metal will feel repulsion from the oxygen and move away from the surface; this lack of negative charge will induce a region of net positive charge closest to the oxygen atom that will attract it to that region, dragging the entire molecule towards the surface. The result is the appearance of an attractive force between the water molecule and the metal that we can identify as an adhesive force.

In a similar way we can work out what will happen when the closest part of the molecule is a hydrogen atom. The positive charge of this atom will attract the free negative charges in the metal, creating a negative region next to the positive hydrogen atom that will exert a corresponding attractive force on it. As in the previous case, we can identify the force as adhesion.

It is very easy to relate these phenomena to those of the movements of charge in the drinks can when it comes close to an electrified bar that polarises it by induction.

We will now consider surface tension as the resistance of the surface of a liquid to being crossed by an object.

As a result, the surface is able to support light objects. In addition, the electrical forces of attraction between surface molecules try to contract the surface, in the same way the rubber of a balloon does, which explains our elastic skin model (Figure 52).

Why is the surface of the water so elastic?

Figure 52. Observing surface tension.

Surface tension is also responsible for the spherical form of drops.

We should use the same model to explain adhesive forces, trying to understand why water sticks to some surfaces more strongly than others.

We can divide surfaces into two types: those that are metallic in nature (and therefore conductors), and non-metal surfaces, formed of molecules that can either be polarised or completely devoid of poles.

In the case of conductive surfaces, the charges of the water molecule will (conductively) polarise the surface they are in contact with, forces of attraction appearing that are similar to those that became apparent between the electrified bar and the drinks can.

In the case of polar surfaces, like glass, it is easy to explain the adhesion: the hydrogen atoms will be attracted by the negative molecules forming the surface and oxygens by the positive ones. The greater or lesser degree of electrical polarisation of the molecules at the surface is responsible for the corresponding magnitude of the adhesion forces.

And, finally, we can look at the case of non-polar solid surfaces, such as wax, paraffin, or oiled paper. In this case, no forces of adhesion appear, since there are no intermolecular forces. This is also why oil and water do not mix. In this case, we can say that the water does not wet the surface.

3.1. CONSIDERATIONS: THE PIAGETIAN STRUCTURE OF HISTORY AND THE DIDACTIC ORGANISATION OF KNOWLEDGE

As we have seen, it is not always advisable to stick rigidly to history to develop a classroom application.

The process of replacing a law or set of laws by other new ones should be studied in a certain degree of detail, as it is the only way to generate knowledge.

The laws of Thales explained the results of experiments right up to 1624. When they were used to try and explain new results (from Cabeo, Gray, Desaguliers, and Dufay) the laws failed and it was necessary to come up with others, and even introduce a new principle (as Franklin did) that allows us *to explain them*. Piaget introduces this process of law substitution as a process of generating knowledge and divides it into the following steps:

1. Situation in which the known laws explain the totality of experimental results available. The *real world-mental representation* system is in equilibrium.

2. New discoveries are produced in the form of new experimental results. Attempting to explain the new results with the old laws leads to their failure, producing an *imbalance* between the behaviour of the real world and the representation that we have developed in our mind.

3. As a result of this imbalance, a new set of laws are necessary that allow our mental representation to *adjust* to the real world.

4. This new system of laws must explain both the old results and the new ones.

5. Upon finishing the process we have a new scheme that *explains* a greater number of experimental results, in other words, more of the real world. Once again we are in a situation of equilibrium.

However, laws are no more than laws, that is, they provide no explanation of why they are like they are, and they never generate more knowledge than that inherent to them. Indeed, we can say that knowledge is generated when an experimental result is found that contradicts existing laws and obliges us to modify them through a process of adjustment. **The field of scientific research is probably the only place where laws are made to be broken**, and research consists of looking for their flaws.

At a higher level than laws, are theories. A theory is formed by a model (in our case the molecular one) whose elements obey the laws of other, already-consolidated disciplines.

A mental model is, as we have said, a representation of the world using icons or symbolic images. We have used marbles and students to represent molecules, and the bonds between them or the table to represent intermolecular forces.

Based on the models, we can deduce already-known laws, which are quantitative relationships fulfilled between the magnitudes making up the model.

Therefore, molecules have electrical charges, they obey the laws of electricity and move and collide according to the laws of mechanics. For a theory to be considered appropriate, the lower level laws should be deduced from it (in addition to any new processes and laws that may not yet have been discovered). In the case we have been studying, above molecular theory is atomic theory and, at an even higher level is the standard model (in fact the theory). In this way, theories (sometimes called theoretical models) are arranged like the layers of an onion. On the outside is cutting-edge science, and as we move inwards we find the level of textbooks, which become more elementary the deeper the level at which they are located[8].

3.2. WHAT DO LAWS EXPLAIN?

Laws do not explain anything: they serve to predict the result of experiments. But, as we can see, they do not do this directly, because the chain of intermediate processes that occurs in such an apparently simple phenomenon as the attraction of confetti by an electrified bar may require the application of several laws and properties.

[8] Sometimes one distinguishes between gas and steam, depending on their temperature. Steam can be liquefied with a simple pressure increase, whereas the temperature of a gas must be lowered in order to liquefy it. However, in this case the distinction is not important.

4. CONCLUSIONS

In this project we have been able to investigate the capacity of children to visualise the world they cannot see with their eyes, for which reason all the activities described deal with the difference between the macrocospic and microscopic worlds. We discover how the world works and what it is made of, in other words, we set off on a journey through the matter that appears to us in the solid, liquid, gas, and plasma states.

In the research carried out by the students, they find out what water is made of, what forces act when a drop sticks to another substance, what happens during evaporation, and how a paper clip can be supported by water. In this way they discover, in a simple manner, that the world is made up of atoms, molecules and crystals that our eyes are not able to see but which are real, and we have to understand how they work.

SECOND PART

FROM TRAINING TO THE CLASSROOM: PRACTICAL APPLICATION

INTRODUCTION

In this second part of the guide *How to bring science into the pre-school subject: 'What is the world made of?'*, we are going show what really happened in the practice in our partner educational centres, and to establish a common method based on the research that took place in the classrooms.

Starting with some simple experiments, we set off down the pathway of questions relating to the facts observed and which allowed the children to construct theories and models to explain the world around them. In the examples we describe below, the pupils took an active role throughout the research into the behaviour of water in various situations in the physical world.

Beginning from the face-to-face training that our partners received at the start of the project, and which is included in the first part of this guide, these proposed experiences respond to pedagogical criteria as well as the cognitive ability of the students. They were distributed in the following way:

- **Preschool P34 'Mali odkrywcy' (Bydgoszcz, Poland)**. What sticks water to other objects? Cohesion and adhesion experiments. The main aim of the research experience in this case was to discover forces that we cannot see with our eyes.
- **San Francisco Public School (Pamplona, Spain)**. Water in the presence of other objects. The aim here was also to discover the forces of adhesion and cohesion. The experiments carried out were related to the discovery of these forces.
- **Asunduse Lasteaed Preschool (Tallin, Estonia)**. The aim of the experiments carried out in the Estonian school was directed towards discovering the existence of things we cannot see with our eyes. To do this, they did experiments to discover the existence of molecules and electrical charges.
- **Kedainiu lopselis-darzelis 'Zilvitis' (Kėdainiai, Lithuania)**. The school in Lithuania did experiments with water to find out about condensation and evaporation, discovering the molecular model and going as far as the water cycle.
- **Teacher and Resources Center (CPR) of Gijón-Oriente (Gijón, Spain)**. The aim here was to discover that the forces of adhesion and cohesion are electrical in nature.
- **KPCEN (Bydgoszcz, Poland)**. Development of teacher support material for the project "What is the world made of?"

Firstly, in Part 1, we describe the general scheme that any teacher should use to collect the material produced during the scientific research they undertake in their classroom. This scheme was sent to all our partners to be used as a model.

In Part 2, we detail conclusions on the results observed with regard to the research.

PART I

TEMPLATE TO BE USED IN ALL DOCUMENTS DESCRIBING SCHOOLROOM ACTIVITIES

In Part 3, each partner presents the results of their research projects, as practical examples of how the first part of this guide was translated to the the classroom, according to the general scheme proposed.

Each document must contain the following sections:

1. Title of the research project

Example: *Discovering surface tension*.

2. Description of the activity

This should include the total number of hours spent on the project, the school where it was carried out, the number and characteristics of the teachers involved, the resources used, the methodology used, the literature utilised, a description of the groups of students, and so on. Below there is an example of the information required for describing the group of students:

Number of students (boys and girls), age range, specific conditions, and any other information describing the characteristics of the group.

3. Purpose of the research project

The objective of the research should always include scientific content, the experimental methods followed, and the structure of the scientific knowledge. The objective can be specific (*like measuring surface tension*) or more general (*like discovering the laws of electricity, the structure of scientific knowledge with magnitudes, laws, models, and theories, or describing the way scientists organise and perform their research work*).

4. Development and preparation of the research activities

Describing how the students carried out the activity or activities.

4.1 Assessment of the state of knowledge of the students before starting the activity, considering both the content and the structure of the scientific knowledge (NOS).

4.2 Description of the methodology used. To clarify this, we have provided an example of how to describe the methodology involved:

a) The first task is an **analysis of the ontology (set of concepts)** needed in the application, organised as a Novak map:

b) Next, the corresponding **concept map** should be drawn.

In the concept map, the top (or final) level consists of the concepts necessary to describe the process that is the objective of the application, using scientific magnitudes. The lowest (or starting) level must reflect the concepts which are meaningful to the students *ab initio* (Ausubel level). In order to meet the requirements of meaningful learning, the teacher should design a constructive path between the Ausubel level and the final level.

If the age of the students permits, the teacher can explicitly indicate the form in which a concept becomes magnitude: measurement process, units, and so on.

c) The importance of inquiry in research work: The Nature of Scientific Inquiry (NOSI).

To begin with, the teacher should choose a challenging experiment. This serves both to awaken the interest of the students and to assess any prior knowledge they may have on the subject. For example, when studying electricity, a stimulating starting point could be the Tales experiment.

After performing the provocative experiment, the students should be asked to describe the process in their own words, answering the standard questions:

What happened?
How does it happen?
Why does it happen?

d) Uncovering the misconceptions

From the answers given by the students, the teacher should evaluate the prior knowledge of their students, their Ausubel level and their capability of using language to precisely describe what they have seen while, at the same time, assessing the existence of misconceptions. These misconceptions must be deconstructed using classroom discussions, supported by suitable experiments designed ad hoc.

e) The experimental path

The teacher, using the Socratic Method, must direct the students towards designing the experiments necessary to answer the standard questions, which will also be useful for constructing the new concepts necessary and discovering laws and models, all according to the age of the learners. This experimental pathway, guided by the questions above, is what defines research work, and must be adjusted, as far as possible, to the historical pathway followed in the scientific process.

Throughout the educational trail, experiments suitable as evaluation exercises will be introduced to check the students' assimilation of the knowledge acquired. These exercises should be performed after presenting the most important or particularly difficult concepts.

5. Final assessment of the activity

In order to ensure that the learning process has yielded the expected results, the teacher must propose a new experiment, hitherto unknown to the students, the explanation for which requires the top-level concepts on the Novak map. The students should not only identify the concepts but also apply the laws, models, and theories (as contemplated in the PISA proficiency tests) needed to theoretically explain why and how the process has taken place.

In the case of electricity, an appropriate assessment could be Franklin's bells, an experiment in which every concept is needed to explain what is happening. The assessment consists of comparing the level of knowledge gained by the students with their initial state of knowledge. No persistent misconceptions should be detected.

6. Final considerations

Any drawings, pictures, graphs, or records made by the students during the development of the activity should be included in the report. All this

PART 2

RESULTS AND CONCLUSIONS FROM THE CLASSROOM EXPERIENCES IN ACCORDANCE WITH THE GENERAL SCHEME PRESENTED

graphic material must be accompanied by the corresponding descriptive text.

It is compulsory for each partner to get the parents' permission to publish the photos of their children.

As we established in the introduction, our partners put into practice the experiences proposed by the coordinators, based on the training they received, to show that whatever country in the European Union they come from, and independently of social and economic conditions, language, culture, religion, sex, and so on, with good scientific training and a suitable method, teachers can introduce science to the classroom right from the earliest stages of education. It is the job of the teachers to understand what degree of knowledge they can achieve with their students, based on their current cognitive stage, according to those described by Piaget.

All these considerations can be found in the guide *Scientific literacy at school: a proposal for a new methodology,* together with recommendations for establishing common criteria for science education, applicable to the European Union.

Returning to the reality of our partners' classrooms, the results obtained in all the experiences demonstrate how, through experiments and following different pathways, they all reach common conclusions, where the children were the true investigators and discovered, on their own, laws, models, and theories adapted to their cognitive stages.

The conclusions that can be extracted from the classroom application in line with the expected results of the project are:

1. Acknowledgement of a change of attitude toward science by teachers, reflecting on the need for prior training.

2. Teaching staff acceptance and assessment of the science training received at the beginning of the project on the two scientific subjects proposed: *What is the world made of?* and *Archaeology in the classroom*.

3. Positive consideration of the new way of seeing the world from the microscopic perspective; you can teach about nature and discover what it is by carrying out very simple experiments related to everyday life.

4. With regard to the students, the teachers have verified that these issues can be addressed in classrooms and that children are very capable of building scientific models adapted to their educational level.

5. Children represent another way of seeing the world through their drawings, particularly the world they cannot see with their eyes.

6. It is increasingly necessary to introduce

science teaching beginning in early childhood education, as children tend to ask questions, solve problems, and question everything they observe.

7. The teachers report changes in the thought processes of the children when faced with science. It is no longer ‘magic’, but ‘science’.

8. A myth is shattered: science is fun; even though learning can be enjoyed, the teaching of science is used to show how to think and solve problems, in other words, it involves changes in the way we think in order to construct knowledge.

9. We have seen that boys and girls both respond in the same way and with the same interest in scientific learning, something that coincides with the results of the latest research[1].

10. From the teachers' responses to the Lederman questionnaires, we can see a clear need for them to acquire a deeper vision of science, based on their own structure (Nature of Science). It is very necessary to determine a nucleus of scientific content in European Union curricula for training non-university teachers.

To close this part, we conclude with a reflection. Teachers are in a privileged position to influence society, as their role is to transmit to future citizens the knowledge and attitudes necessary for them to be able to live their lives in a technological and highly sophisticated society, in other words, to ensure their students acquire what **Lederman** and **Charpak** call *scientific culture*. In addition, as early stage education requires the active participation of families, the ways to focus the problems and the same teaching philosophy reach virtually all citizens within the European Union. Specific knowledge is structured around a way of thinking and a values scheme that are only acquired naturally at a young age. This coincides with the age the socialisation of students takes place.

Radio signals are sent to our televisions, mobile phones, and radios, or interconnect our devices via *bluetooth*; ultrasounds open and close our garage doors and help us form sonogram images; and x-rays let us see inside our bodies. All these are part of the daily lives of students in early educational stages. The aim of this guide is to help the children develop in a world that, predominantly, falls beyond our senses.

[1] Bian, L., Leslie, S-J. and Cimpian, A., 2007. Gender stereotypes about intelectual ability emerge early and influence children’s interests. *Science*. 355(6323), pp. 389-391.

PART 3

RESEARCH CARRIED OUT BY PARTNERS

TEACHERS AND RESOURCES CENTER OF GIJÓN-ORIENTE (ASTURIAS, SPAIN).
DISCOVERING THE LAWS OF ELECTROSTATICS

1. COORDINATOR'S INTRODUCTION

The example selected from a Gijón CPR centre is the research carried out by the Grouped Rural Centre (Centro Rural Agrupado, or CRA) Eugenia Astur-La Espina, in Asturias. The research was carried out by a teacher and their class, which included students of various ages as this Rural Centre groups several class years together.

Under the title 'Invisible Forces' the teacher's aim was to introduce the concepts of the electrostatic models, laws, and theories to the children. Starting with a thought-provoking experiment, rubbing a plastic pen and putting it close to some little pieces of paper, they began down the investigative path. Carrying out other experiments related to this topic, the teacher led the children towards the discovery of certain laws of electricity, but it was always the children themselves that discovered these, in a constructivist and experimental manner.

2. METHOD USED IN THE RESEARCH

Before starting the research, the teachers drew up a Novak map, in other words, a conceptual map of the phenomena we wanted to discover in this project. The map structure was constructivist and defined our experimental path. We developed a guide including the investigative steps to lead the students to the discovery of the laws of electricity. This guide comprised:

- Casual observation: awakening interest.
- Experiments 1, 2, and 3.
- We invented a name for the phenomenon that we had discovered.
- We introduced new concepts.
- Experiment 4 for assimilating knowledge.
- New concepts.
- Conclusions.

3. DEVELOPMENT OF THE RESEARCH PROJECT: DISCOVERING THE LAWS OF ELECTROSTATICS

The research was carried out by the teacher Miguel Ángel Moreno in his classroom, with a group of 13 children, during the school term.

3.1. THE RESOURCES

The resources used were: pens, small pieces of paper, napkins, paperclips, nylon cord, balloons, soft drinks cans, PVC bars, aluminium foil, skewer sticks.

3.2. MAIN REFERENCES

The main references used included the CSIC virtual classroom (www.aulavirtual.csic.es), as well as the CSIC at School website (www.csicenlaescuela.csic.es) and KIDS.CSIC.es (www.kids.csic.es).

3.3. GOAL OF THE RESEARCH

Goal of the research was to use models, theories, and laws to introduce the children to the laws of electrostatics.

3.4. START OF THE RESEARCH: DESCRIPTION OF THE THOUGHT-PROVOKING EXPERIMENTS AND RESULTS

We began the research with an experiment that motivated and grabbed the attention of the children. We rubbed a pen on our jumpers and put it close to some little bits of paper. This is a phenomenon we all have played with in class, but have never asked ourselves what was happening. The children gave various answers:

— *I think that rubbing the pen generates static electricity. It's not magic, it's science.*

— *Rubbing the pen generates static electricity.*

— *Rubbing the pen against our clothes produces a force which is why the bits of paper stick to it* —It is interesting that this student indicated the fact we are dealing with a 'force'.

All the students had some idea of static electricity, but it was necessary to do more research to discover the nature of this force.

We took the opportunity to define what an experiment consists of: it is a set of processes prepared or designed (in the laboratory) to increase our knowledge to explain naturally occurring phenomena.

What we had done beforehand, in a casual way, was an experiment. Now we did this more consciously.

3.5. DESCRIPTION OF EXPERIMENT 1: LOOKING IN MORE DETAIL AT THE THOUGHT-PROVOKING EXPERIMENT

Previously, we had rubbed the pen on our clothes straight away. The idea was now to repeat the experiment by putting the pen close to the pieces of paper without rubbing it first. We wrote down the results in our notebooks.

Next, we rubbed the pen on our clothes and put it close to the paper, a paper napkin, our classmates' hair, and so on. We observed what happened and wrote it down.

As a conclusion, we observed that it is necessary to rub the pen for this 'force' to act. But why?

3.6. DESCRIPTION OF EXPERIMENT 2: DOES THE PEN ATTRACT OTHER THINGS?

For this experiment, we tied a nylon cord to a paperclip and, after rubbing the pen, we saw that the pen and the clip go towards each other. We observed that the same thing happens as with the pen and the little pieces of paper.

To investigate further, we did a third experiment.

3.7. DESCRIPTION OF EXPERIMENT 3: THE BALLOON AND THE DRINKS CAN

First, we took an inflated balloon that we had not rubbed and put it close to an empty drinks can. We saw that nothing happened.

Then we repeated what we had done with the pen. We rubbed the balloon and put it close to the can. The can started rolling toward the balloon. We observed that the can 'moved' towards the balloon.

We used the same balloon we had rubbed and put it close to the paperclip. We saw that this too moved towards the balloon.

After carrying out these three experiments, it was time to analyse what had happened. We asked the children the following questions:

- *What differences do you see when you rub the balloon or you don't?*
- *What could you call the phenomenon we have observed?*
- *What relationship do you think exists between these phenomena and the electricity that comes into our homes?*

The students gave various different answers. The children said the following things about the balloon and paperclip experiment:

— I notice that the balloon and paperclip do not stick together if you do not rub the balloon, but they do stick if you rub it. I would call it 'the force of energy', and I think its relationship with the electricity that comes into our home is that 'there is something that attracts electricity to our house just like the balloon and the clip'.

Another student said:

— I would call it the "clip phenomenon" and I think that its relationship with the electricity in my house is that there is an electric current in both.

3.8. DISMANTLING PRECONCEPTIONS

We explained to the children that when an object, after being rubbed with a cloth or paper, is able to attract smaller objects (we use the correct language, instead of 'stick'), we say that it is electrified. In contrast, if the object does not have this property (it does not attract them), we say that it is neutral. At this point we needed to do further research on these properties.

To do this, we continued doing experiments, rubbing other objects and seeing what happened: a wooden pencil, a copper bar, etc.

New questions came up immediately:

- *Are there materials that electrify when rubbed and others that do not?*
- *What does "attract" mean?*
- *What is the attraction between two bodies? Is it a force? Is it visible to the human eye?*
- *If we rub a pen or balloon even harder, does it attract more little bits of paper? Does the can 'walk' faster?*
- *Does it mean that the electrified object increases its attractive force?*

The children's replies were similar in all cases. They all saw clearly that some objects were electrified by rubbing and others were not. Everyone agreed that the attraction between two bodies is a force. They defined attraction in different ways, but with the common idea that one body approaches another without needing to be in contact. The last two questions generated the most controversy as there was a difference of opinion in the class.

3.9. INTRODUCING NEW CONCEPTS

The students had to admit that there must be "something" inside the materials that causes certain objects to become charged while others are not.

After the experiments, we introduced the concept of electric charge, defining it as the amount of electricity an object has. We introduced a new magnitude: the force exerted by an electrified body on another neutral body is called electric force. The more the electrical charge, the more the electrical force. Force is a magnitude because we can measure it.

We stopped our journey to look at the concept of laws, focusing on the law of Gravity, discovered by Isaac Newton and which is, described simply, the force with which the Earth attracts masses. It is a law because it is always fulfilled.

3.10. WE CONTINUED OUR RESEARCH TO ARRIVE AT THE LAWS

Some students noticed that as time passed, the electrified object stopped attracting the neutral one:

- *What happened?*
- *Why did this happen?*

Some of the responses were:

— *Because it transmits energy to the other body.*

— *Because it loses its electrical charge.*

— *Because the electrical charge passes into the little bits of paper.*

To find out what was happening, we did more experiments, this time bringing a balloon and a pen close to two pieces of aluminium foil folded over a skewer, as shown in the photographs.

Figure 1.

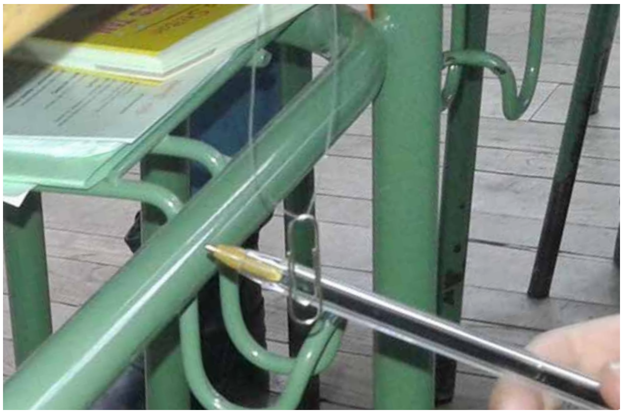


Figure 2.

Figure 3.

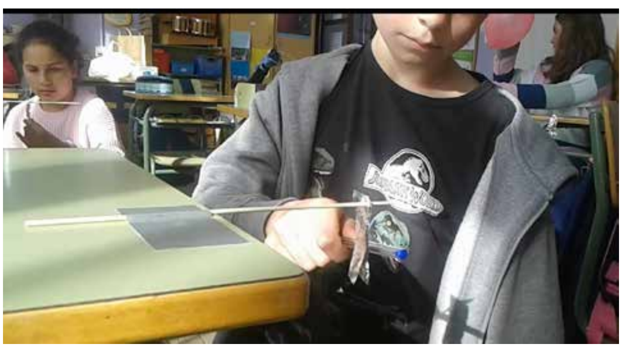


Figure 4.

The students thought about whether the pieces of paper would be attracted by the balloon or the pen. After repeating the experiment with different balloons, pens, and pieces of aluminium foil, they observed that the aluminium foil always moved away.

Through this experimental method that the students followed themselves, they realised that there was another force. They gave it a name: force of repulsion.

3.11. CONCLUSIONS FROM THE RESEARCH

Step-by-step we were able to reach conclusions thanks to the path we took:

1. When we rub a body, this becomes **electrified** (in other words, it has an electric charge).

2. When we put an electrified body close to a neutral body (non-electrified) there appears what we call **electrical force**. This could be:

   - **Attraction**.
   - **Repulsion**.

   In addition, we observed various ways of making a body electrified:

   - By rubbing.
   - Induction.
   - Contact.

   The question now was: do all bodies have electrical charges? The students generally responded in the affirmative, commenting on the experience that we have all had at some point when touching an object and feeling a ‘spark’.

   We explained to the children that there are two types of charge: positive and negative. Normally bodies are electrically neutral, in other words, they have the same number of positive and negative charges. For a body to be electrically charged it must be because either its positive charges exceed the negative ones or vice versa. When we rub a body, it loses some of its negative charge and we say that it is positively charged.

In contrast, when a body gains negative charge, we say that it is negatively charged.

The next step in the research was to analyse our experiments and think about what had happened, imagining the structure of matter from a sub-microscopic perspective.

The children saw that, when they rubbed the pen, it became charged, either positively or negatively.

But in order to attract paper or repel aluminium foil, something had to happen to the charges. In this way, on their own, they discovered the laws of electricity:

- Charges with the same sign repel.
- Charges with opposite signs attract.

Forces of attraction and repulsion between bodies are therefore established. Once again we stated the laws:

- Two electrified bodies with the same sign repel one another (the aluminium foil).
- Two electrified bodies with different signs attract each other (the pieces of paper and the pen).

KEDAINIU LOPSELIS-DARZELIS 'ZILVITIS' (KĖDAINIAI, LITHUANIA).
EVAPORATION AND CONDENSATION: THE WATER CYCLE

1. COORDINATOR'S INTRODUCTION

The research project carried out by the Lithuanian infant school responded to what the students discovered about the water cycle and went as far as the molecular model of water. The research pathway was constructivist, with the children taking the lead role.

Thanks to suitable training, the teachers who carried out the experiments with the students were able to lead them to the discovery of evaporation and condensation, starting from a simple and provocative experiment, such as observing the puddles formed on a rainy day. Doing this favoured the introduction of the water molecule concept while simultaneously introducing a natural phenomenon and responding to the question: Why does it rain? In reality, science does not deal with *why*, but rather *how*, so when the students discover the water cycle, they are in fact discovering how rain is produced.

2. COMMON METHODOLOGY USED IN THE PROJECT

Before initiating the research pathway, the teachers developed a conceptual map of the phenomenon to be studied. This map has a constructivist structure and indicates the experimental path necessary to introduce the different concepts according to the cognitive stage at which the children are, according to Piaget.

The conceptual map developed was, in order:

1. Specific properties that differentiate solids from liquids.
2. Specific properties of water.
3. States of matter: solid, liquid and gas.
4. The state changes of water: evaporation and condensation.
5. Water is formed by molecules (moving from the macrocospic world to the microscopic one).
6. The water cycle.

3. DEVELOPMENT OF THE RESEARCH PROJECT: 'EVAPORATION AND CONDENSATION: THE WATER CYCLE'

3.1. DESCRIPTION OF ACTIVITY 1: WHAT HAPPENS IN A PUDDLE?

What happens in a puddle?

The research project took 2 days. 1 pre-school teacher organised the activities. 16 creative and enthusiastic children aged 5-6 participated in the project. They offered progressively more imaginative ideas about how to carry out the tasks, make things or solve longer-term or more abstract challenges. The children enjoyed participating in a variety of new experiences.

The resources used while conducting the project were the following ones:

- Chalk.
- Measuring tape.
- http://www.kidzone.ws/water/bactivity1.htm
- https://www.aulavirtual.csic.es/
- http://www.csicenlaescuela.csic.es/
- https://www.youtube.com/watch?v=FAnDlYRycqs
- https://www.youtube.com/watch?v=_TwKDuozJC4
- https://www.youtube.com/watch?v=Vm6HthxtzPw

Purpose of the activity

Following the experimental path, the research project began with a provocative experiment observing nature. The idea was to discover if, and how, water evaporates from a puddle, to lead the children towards the idea of evaporation.

Preparation and elaboration of the research activities

In order to conduct the research project we used the scientific method of observation, questioning, hypothesis, experimentation and analysis. Conclusions were drawn after the completion of the research.

In the morning the kids went outside where there were a lot of puddles. A few kids were wearing boots, so they enjoyed splashing around and running in the puddles. They observed the size of the puddles.

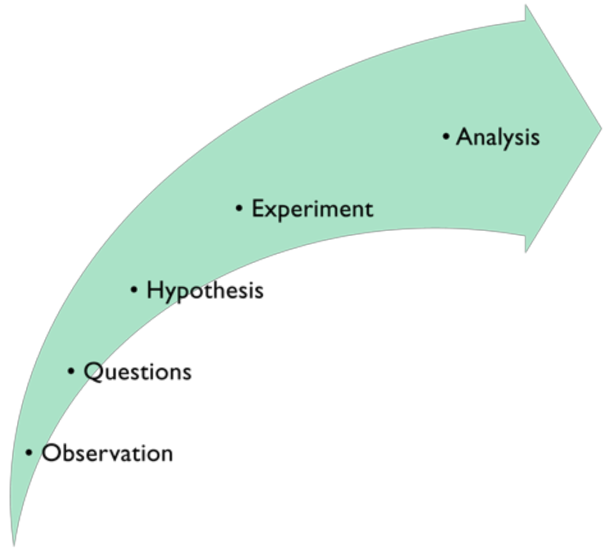


Figure 1. The stages of activities.

The kids remembered that there had been puddles the day before, too, but that they had been bigger. More questions came up (Figure 2).

The teacher used the Socratic method and using the dialogue form asked the kids some questions:

- *What happens to wet laundry?*
- *When your shoes are wet what do you do?*
- *Where do you put your umbrella when it is wet?*

They were eager to know where the water from a puddle disappears to, and how much time it takes. In order to find out the answers, we started our experiment. First, we used chalk to draw a cline around the puddle. The kids took the measuring tape, measured the length of the puddle, and wrote down the figures.

Figure 2. More questions came up.

In the afternoon the children measured the puddle again. We compared the measurements and found out that the puddle had become smaller by the afternoon.

The kids played a number game and jumped over the puddle. They all agreed it was easier to jump over the puddle in the afternoon because it was smaller. When we went back to the group we had a discussion about water evaporation. We watched a story about a little rain drop, remembered the material from the previous lessons about the water cycle and finally the kids depicted everything in their drawings. Through the discussion and examples the children themselves gave the right answers: *when something is wet we need to dry it and water disappears back into the air and this means it evaporates*.

They realised that water evaporates. Two days later the kids went outside and they saw that the water from the puddle had disappeared and they could only see wet ground.

Final assessment of the activity

The children used their own words to explain what happens when water escapes from the puddle. They realised that evaporation is important in the Earth's water cycle. Water falls from the sky in the form of rain (or if it is cold, sleet, hail or snow). The water evaporates back into the air as it warms up -although we know that water evaporates constantly (Figure 3).

Figure 3. Drawings.

3.2. DESCRIPTION OF ACTIVITY 2: WHERE HAS THE WATER GONE THAT HAS DISAPPEARED FROM THE LAUNDRY?

This is the continuation of the previous activity in order to set the ideas. The research project took 2 days. 2 pre-school teachers organised the activities. Twenty energetic, talkative and curious children aged 4-5 participated in the project. There were 11 girls and 9 boys. They constantly test their environment. They learn about new things through games and while playing.

The resources used in the activity were the following:

- Bowls.
- Water.
- Dolls.
- Clothes.
- A rope.
- https://www.youtube.com/watch?v=Y9uOLkivcfw
- https://www.youtube.com/watch?v=TWb4KlM2vts
- https://www.delfi.lt/video/laidos/animacija/animacinis-filmas-vandens-lasas.d?id=62473607
- https://www.aulavirtual.csic.es/
- http://www.csicenlaescuela.csic.es/

Purpose of the research project

To set the concepts that the children acquired in the previous activity with another activity involving the evaporation process. Again, an everyday phenomenon was used: how laundry gets dry in order to explore how water evaporates.

Preparation and elaboration of the research activities

After researching the puddles, the kids' interest was already awakened. The teacher took a sheet of plastic and using a pipette asked the kids to add drops of water to it. After that the sheet with the drops on was put on a windowsill. The teacher asked questions:

- *What will happen to the drops?*
- *Why did we choose the windowsill?*

The curious children gave their own answers.

Uncovering misconceptions

Several kids explained that the drops would remain and form a puddle, others thought that nothing would happen, a few said the drops would *escape*. The teacher told them that they would see the final result in an hour. Then the kids sat in a circle and listened to the story of a rain drop's journey, in Lithuanian. After that the kids played a game called 'We are little drops' and then prepared and choose clothes for the dolls.

Stages of the activities

The teacher, together with the kids, poured some warm water into the bowls. Then the children took the clothes off the dolls and washed them.

They rinsed the clothes with clean water and tried to wring them out with the help of a grown-up. Some clothes were hung inside in the washing room and a few dresses and a shawl were taken outside and hung on a string.

In the afternoon the children checked the clothes that had been hung inside.

Figure 4. Washing clothes.

The clothes were still wet. The children explained:

— *There is no sun.*

— *They were cold.*

— *It's not hot here.*

— *There was no wind.*

— *There were no clouds.*

So, we decided to take the clothes outside. It was a sunny day.

The children's responses were really important. We observed the laundry outside, and it was dry. The children said:

— *The sun heated the laundry and the water evaporated.*

— *The wind blew out the water.*

— *Now the water lives in the cloud.*

— *I couldn't see how water has evaporated.*

— *Vapour is invisible.*

Final assessment of the activity

The children explained:

— *Water can be in the gas state, which is invisible. Water evaporates.*

The children drew these conclusions:

— *Vapour is in the air.*

— *Vapour forms when the temperature rises.*

— *Vapour can't be seen.*

The next step was to help the children understand that the laundry inside would also dry, but that this process would take more time because there is no sun in the classroom. Evaporation is accelerated by heat, but water evaporates constantly.

3.3. DESCRIPTION OF ACTIVITY 3: DISCOVERING MOLECULES

The research project took 2 days. 2 pre-school teachers organised the activities. 34 creative and enthusiastic children aged 4-6 participated in the project. These children are imaginative, curious and eager to find the answers to the questions they have. The children enjoy participating in a variety of new activities.

The resources and materials used while conducting the project were the following:

- Pencils.
- Disposable glasses.
- Paper.
- Water.
- https:/www.youtube.com/watch?v=FFbJ8REc9jo.
- https://www.aulavirtual.csic.es.
- http://www.csicenlaescuela.csic.es.

Purpose of the research project

After discovering that water evaporates and heat accelerates this process, the next step in the investigation was to discover the nature of water and arrive at the concept of a molecule.

Preparation and elaboration of the research activities

We started our research early in the morning. We went outside and observed the rain drops dripping from the roof. The children took glasses and began gathering the rain drops from the roof in their glasses. The glasses were transparent so it was not difficult to count the raindrops and observe them.

Later we measured who had the most water in their glass and found out that Arnas had won. The teachers told their students that water is made up of very small particles. These are too small to see with our eyes, and are made up of molecules. In this way we took the step from the macroscopic to the microscopic world.

The teachers told the children that those drops of water meant they had a lot of molecules in their glasses.

When we went back to the class, the children depicted the rain drops in their drawings. They made lively, colourful raindrops, and added arms and legs. We prepared an exhibition.

In the classroom, we represented how the molecules inside the drops move. The teacher explained that the molecules merge together in liquid water but during the process of evaporation they separate from each other.

The children made cloaks of paper, imagined that they were the molecules, and played a game called *Friendship*.

Figure 5. Children played a game called *Friendship*.

Final assessment of the activity

The research topic was quite difficult for the children because the term *molecules* was new to them. We tried to find out the meaning and make it clear in a way the kids could understand. The children realised that it was impossible to see the molecules but they all said that they really existed in their glasses of rain drops. One boy, called Pijus, explained that the water drops join together and in that way the number of water molecules increases. So the children accepted that there is a world that they cannot see but still exists.

3.4. DESCRIPTION OF ACTIVITY 4: WATER CONDENSATION

The research project took 2 hours. 2 pre-school teachers organised the activities. 35 energetic, joyful 4-6 year-old children participated in the project. They are interested in everything that is new, and they are creative and enthusiastic. They offer great ideas as to how to perform tasks and create things. These children enjoy participating in a variety of new experiences.

The resources used while conducting the project were the following:

- A chilled drinks can.
- A glass.
- Water.
- https//www.youtube.com/watch?v=UbgGbfYVx-E.
- https://www.aulavirtual.csic.es.
- http://www.csicenlaescuela.csic.es.

Purpose of the research project

Once the children have discovered evaporation and the concept that water is made up of molecules, they can be led to discover another fundamental phenomenon involved in the water cycle: condensation.

Preparation and elaboration of the research activities

The teachers had a discussion with the kids. They asked the fallowing questions:

- *What is an experiment?*
- *Why do people do experiments?*
- *Where can we do an experiment?*
- *Why do we need the experiments?*

The children were very curious and gave various answers to the questions.

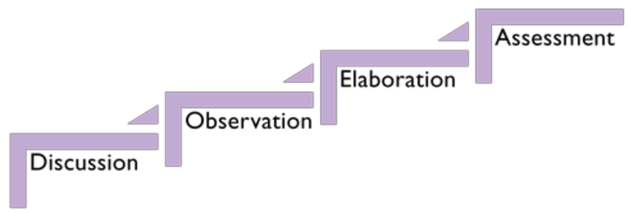


Figure 6. Stages of the research.

The experimental path; uncovering misconceptions

We did an experiment with a can which had been kept in the fridge. We took the can from the fridge and put it on the table. The children observed the can. Soon they noticed water drops on the can.

The teachers asked a question:

- *Where did that water come from?*

As the children had worked on the evaporation process and the fact water is made up of molecules, they replied that the molecules in the air had stuck to the can to form the drops.

Figure 7. Observation of water condensation.

The teacher gave this process a name: condensation.

1. We depicted the process of condensation in drawings.

2. We took a glass, placed small pieces of ice inside and poured in cold water. Drops of water appeared on the outside of the glass. The cold glass cooled the air around it and the water vapour condensed from the air to form water droplets. We played a game called *Warm Cold*.

Figure 8. Drawing of water condensation.

Final assessment of the activity

The children learned that vapour turns into drops of liquid water. At first, the children had a little bit of difficulty understanding the meaning of evaporation and condensation due to their misconceptions, but the experiments facilitated their understanding of these concepts. We played a game called *Vapour and Droplets*.

3.5. DESCRIPTION OF ACTIVITY 5: WHERE DOES WATER COME FROM?

The research project took 3 days. 2 pre-school teachers organised the activities. 38 creative and enthusiastic children aged 4-6 participated in the project. These children are aware of rules and explain them to others. The children enjoy activities requiring hand skills. They are able to work in groups of two to five children.

The resources used while conducting the project were the following:

- http://www.imandra.lt/project/zydrojo-laselio-kelione-i-zeme/
- The book *Žydrojo lašelio kelionė*
- http://eilerastukaivaikams.blogspot.lt/2014/11/pasaka-apie-debeseli.html
- https://www.youtube.com/watch?v=fKCXU8P6aaQhttp://www.kidzone.ws/water/bactivity1.htm
- https://www.youtube.com/watch?v=TWb4KIM2vts
- https://www.aulavirtual.csic.es/
- http://www.csicenlaescuela.csic.es/
- A jar.
- Boiling water.
- A plate.
- Transparent plastic bag.
- Felt-tip pens.
- Ice cubes.

Purpose of the research project

As we had taken a constructivist path in the previous experiments, we moved the model to nature to understand how the water cycle is produced and how evaporation, condensation and precipitation are a fundamental part of this.

Preparation and elaboration of the research activities

Main stages and uncovering misconceptions:

- Discussion: The teachers initiated a conversation with the children to find out what they knew about the water cycle.

- The teacher read the tale *The Journey of the Drop* and a short poem entitled *Cloud*. The children were interested in the activity and the teacher invited them to play a game.

Figures 9 and 10. Experiment *How to make rain*.

- As the children had already worked on evaporation and condensation, they had a clear idea of what happens in nature.

The experimental path

We did an experiment called *How to make rain*. The children took a jar filled with warm water, put a plate on the top of the glass and spread ice cubes on the plate. We observed the formation of water droplets. The children took felt-tip pens and drew the sun, clouds and water on transparent bags. We poured coloured water inside the bag. The next day we had the opportunity to observe the process.

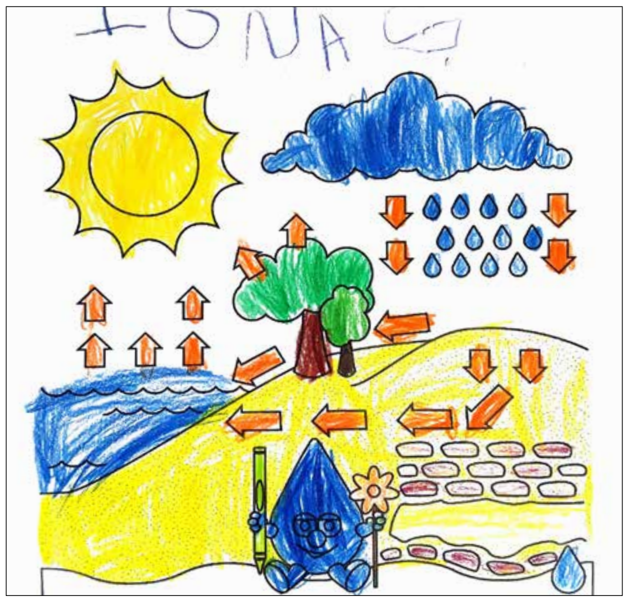


Figure 11. Drawings of water cycle.

Final assessment of the activity

- Children made the experiments actively participating in the activities. They understood the process of evaporation and condensation. When the teacher asked the same discussion questions at the end of the activities, she got more answers and the kids explained the process of evaporation and condensation more easily.

- Water evaporates constantly but the process accelerates when it is sunny.

- Water molecules evaporate and go into the air. The molecules join and form drops that turn into clouds.

- It is cold in the clouds and when the drops are too big, vapour falls down in the form of rain or snow.

- Precipitation soaks into the ground and flows back into rivers and seas.

- The water cycle tends to repeat.

Figure 12. Drawings of water cycle.

KPCEN (BYDGOSZCZ, POLAND), CSIC AT SCHOOL (SPAIN).

WHAT IS THE WORLD MADE OF?

1. INTRODUCTION

This material is a proposal addressed to teachers of early stages of education, in order to manage the teaching of science in the classroom.

The project *What is the world made of?* is addressed to children to make mental representations of the part of the natural world that our eyes cannot see, such as the concept of force. Water, for example, is a very close element for children. Children will discover the properties and behaviour of water with other materials by experimenting and following a constructivist approach.

Note for teachers: These activities have to be done by children. At the end of the process, children have to represent the knowledge they have acquired in their notebooks with their drawings, even if they do not know how to draw at these stages; surely they are able to represent what they think. It is very important to know if they have built knowledge concerning the behaviour of water; it is in their minds where changes and advances occur in the way of thinking about the natural world.

2. EXPERIMENTS

2.1. EXPERIMENT 1. WATER

OBJECTIVE

To discover and conceptualize cohesion and adhesion forces.

PREPARATION

Materials needed: A glass with water.

TASK

Hold some water between two fingers

RESEARCH QUESTIONS

— *What do you notice?*

— *Can we hold water with our fingers?*

— *Why does water stay between fingers; why doesn't it drop?*

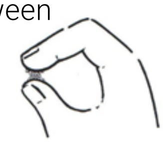
— *Is there any force in water?*

OBSERVATION

Water sticks to fingers.

EXPLANATION

Water keeps forming a drop that does not divide into smaller drops. There have to be forces between the water and the finger. Besides, there have to be forces inside the drop.

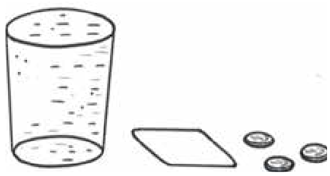


2.2. EXPERIMENT 2. WATER AND A PLASTIC CARD

OBJECTIVE

To consider the magnitude of adhesion forces by comparing with the weight of the coins (number of coins).

PREPARATION

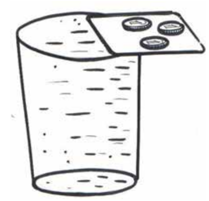


Materials needed:

- A glass fully filled with water.
- A used plastic card, e.g. a bank card.
- A few coins of the same type, 1 penny.

Figure 1.

TASK
1. Put the card on top of the glass fully filled with water, as shown in the drawing.   ***2. Put a coin on the card. Then keep putting more coins on the card, one by one.***
RESEARCH QUESTIONS
— What do you notice?   *— Why does the card stick to water?*   *— What makes the card stick to water?*   *— With what strength does the card stick to water?*
OBSERVATION
EXPLANATION
There are forces of adhesion and cohesion: • ADHESION - forces between the water and the card (one kind of material and another kind of material).   • COHESION - forces inside the drop (or water) that hold the water forming the drop (or water).



2.3. EXPERIMENT 3. WATER AND A COIN

OBJECTIVE

To estimate cohesion and adhesion forces.

PREPARATION

Materials needed:

- A dropper.
- A coin, e.g. a penny.
- Water.

Figure 2.

TASK

Place drops of water on the coin with the dropper.

RESEARCH QUESTIONS

— *What do you notice?*

— *How many drops of water fit on a coin?*

— *Are there any forces between water and the coin?*

OBSERVATION

EXPLANATION

• There is a force working between water and the coin, called **adhesion**. (The same as in experiment 1, between the drop and the finger; the same as in experiment 2, between the water and the card).

• Water 'sticks' to other items.

2.4.A. EXPERIMENT 4.A. FROM A DROPLET OF WATER TO ELECTRICITY

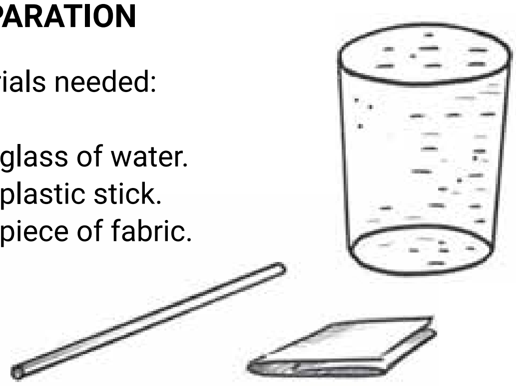
OBJECTIVE

To discover the nature of these kind of forces.

PREPARATION

Materials needed:

- A glass of water.
- A plastic stick.
- A piece of fabric.



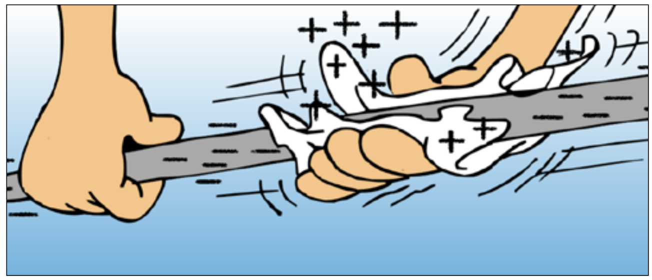
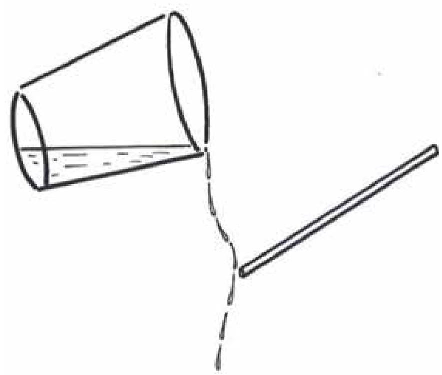


Figure 3.

TASK

1. ***Rub the plastic stick with a piece of fabric.***
2. ***Pour water in a delicate stream next to the electrified plastic stick.***



RESEARCH QUESTIONS

— What do you see?

— Why does the stream of water get closer to the stick?

OBSERVATION

EXPLANATION

- The stick is electrified.
- There is a force working between water and the electrified stick.
- The force is attractive.

2.4.A. EXPERIMENT 4.B. FROM A DROPLET OF WATER TO ELECTRICITY

OBJECTIVE

To discover the nature of this kind of forces.

PREPARATION

Materials needed:

- A glass of water.
- A magnet.

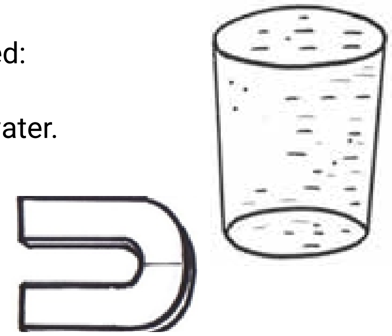
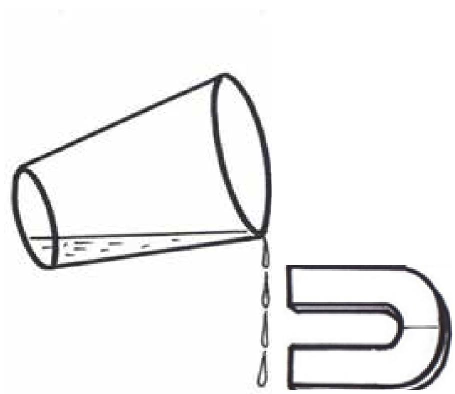


Figure 4.

TASK

Pour water in a delicate stream next to the magnet.



RESEARCH QUESTIONS

— What do you see?

— Why doesn't the stream of water get closer to the magnet?

OBSERVATION

EXPLANATION

• Magnet has no influence on water.

2.5.A. EXPERIMENT 5.A. A PLASTIC STICK AND PAPER

OBJECTIVE

To introduce electric forces.

PREPARATION

Materials needed:

- Pieces of paper.
- A plastic stick.
- A piece of fabric.

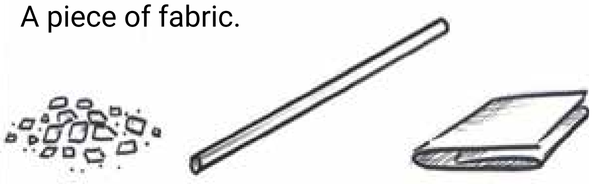
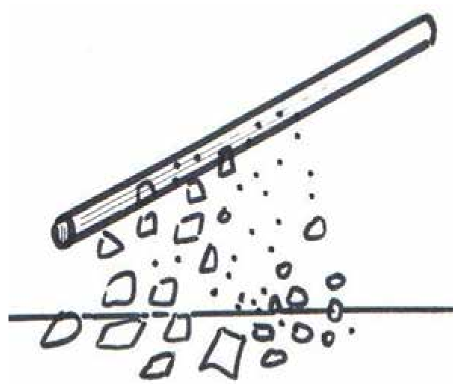


Figure 5.

TASK	
1. Rub the plastic stick with a piece of fabric. ***2. Bring the stick close to the small pieces of paper.***	
RESEARCH QUESTIONS	
— What do you notice? *— Are there any forces between the electrified stick and the pieces of paper?*	
OBSERVATION	
EXPLANATION	
• There is a force between the charged/ electrified stick and pieces of paper. • Electricity.	

2.5.B. EXPERIMENT 5.B. A MAGNET AND PAPER

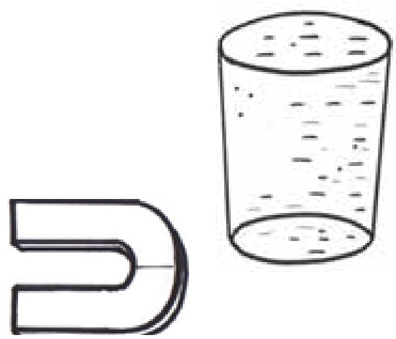
OBJECTIVE

To introduce electric forces.

PREPARATION

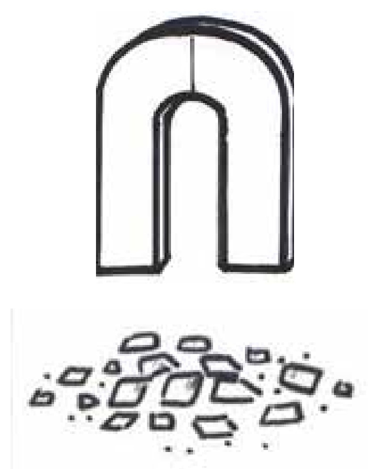
Materials needed:

- Pieces of paper.
- A magnet.



TASK

Bring the magnet close to the small pieces of paper.



RESEARCH QUESTIONS

— What do you notice?

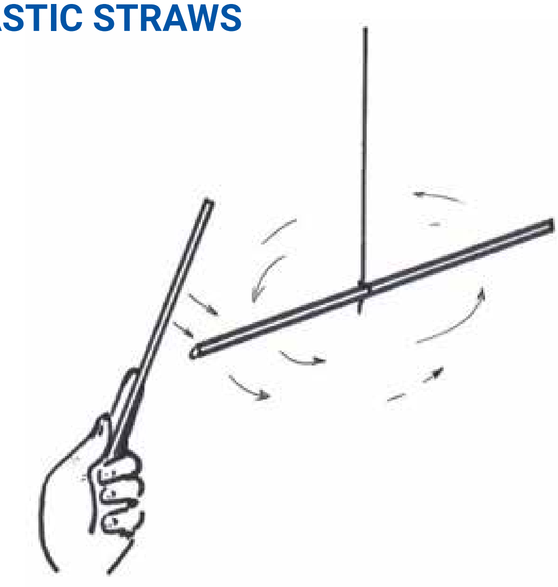
— Are there any forces between the magnet and the pieces of paper?

OBSERVATION

EXPLANATION

• Nothing is happening, because the magnetic forces cannot be applied in this case.

2.6.A. EXPERIMENT 6.A. ELECTRIFIED PLASTIC STRAWS



OBJECTIVE

To discover the laws of electricity.

PREPARATION

Materials needed:

- A plastic straws.
- A piece of clean paper towel or napkin.
- A thin string.
- A marker.

TASK

1. ***Tie a piece of thin string in the middle of the straw, as shown in the drawing. Mark the end of the stick with a marker.***
2. ***Rub the other straw with a piece of clean paper towel or napkin.***
3. ***Bring this straw close to the one hanging on the string.***
4. ***Rub the marked half straw with other paper towel or napkin.***
5. ***Rub another straw with a new napkin.***

RESEARCH QUESTIONS

— What do you see?

— Why do the two straws of the same kind affect each other?

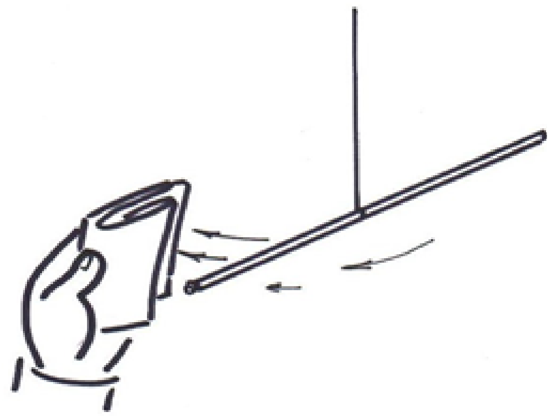
OBSERVATION

Two plastic straws of the same kind attract or repel each other

EXPLANATION

- There is a force between the two rubbed plastic straws.
- The force is negative.

2.6.B. EXPERIMENT 6.B. ELECTRIFIED PLASTIC STRAWS



OBJECTIVE

To discover the laws of electricity.

PREPARATION

Materials needed:

- A plastic straw.
- A piece of clean paper towel or napkin.
- A thin string.

TASK
1. Tie a piece of thin string in the middle of the straw, as shown in the drawing. Mark the end of the stick with a marker.   ***2. Bring a piece of clean paper towel to the straw hanging on the string.***
RESEARCH QUESTIONS
— What do you see?   *— Are there any forces between the paper towel and the straw?*
OBSERVATION
EXPLANATION
The paper towel close to the hanging straw produces an attractive force (contrary to when the two rubbed straws are close)

2.7.A. EXPERIMENT 7.A. A PLASTIC STICK AND SOAP BUBBLES

OBJECTIVE

To check that the water is sensitive/responsive to the electric force.

PREPARATION

Materials needed:

- A water with dishwashing liquid.
- A a plastic stick.
- A a piece of fabric.
- A soap bubbler.

TASK

1. ***Wet the table with water with dishwashing liquid.***
2. ***Make a few soap bubbles on the table.***
3. ***Rub the plastic stick with a piece of fabric.***
4. ***Bring the stick close to the small soap bubbles.***

RESEARCH QUESTIONS

— What do you notice?

— Are there any forces between the electrified/ rubbed stick and the soap bubbles?

OBSERVATION

EXPLANATION

- There is a force between the electrified stick and the soap bubbles.
- The force is attractive.

2.7.B. EXPERIMENT 7.B. A MAGNET AND SOAP BUBBLES

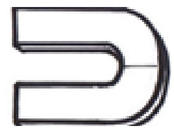
OBJECTIVE

To check if the water is sensitive/responsive to the magnetic force.

PREPARATION

Materials needed:

- Water with dishwashing liquid.
- A magnet.
- A soap bubbler.

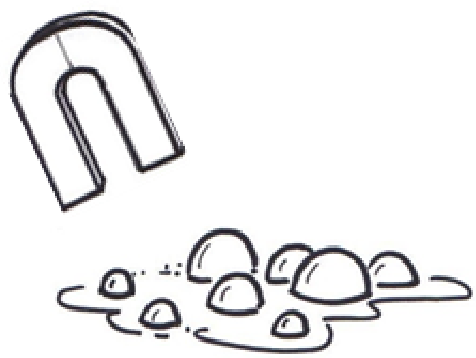


TASK

1. Wet the table with water with dishwashing liquid.

2. Make a few soap bubbles on the table.

3. Bring the magnet close to the small soap bubbles.



RESEARCH QUESTIONS

— What do you see?

— Are there any forces between the magnet and the soap bubbles?

OBSERVATION

EXPLANATION

Nothing is happening, because the magnetic forces cannot be applied in this case.

2.8. EXPERIMENT 8. A PLASTIC STICK AND A METAL CAN

OBJECTIVE

To study the performance/ behaviour of other kind of materials (different than water) when an electrified body gets closer.

PREPARATION

Materials needed:

- An empty metal can.
- A plastic stick.
- A piece of fabric.

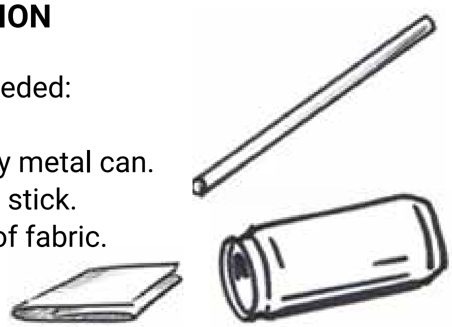
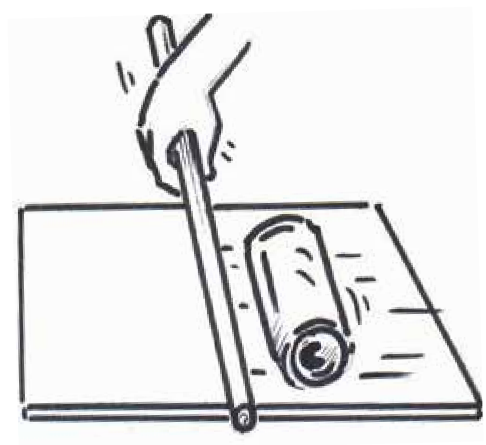


Figure 6.

TASK

1. **Rub the plastic stick with a piece of fabric.**
2. **Bring the stick close to the metal can.**



RESEARCH QUESTIONS

— What do you notice?

— Are there any forces between the electrified stick and the metal can?

OBSERVATION

The can moves, rolls.

EXPLANATION

- There is a force between the electrified stick and the metal can.
- The force is attractive.

2.9. EXPERIMENT 9. ELECTRIFIED BALLOONS

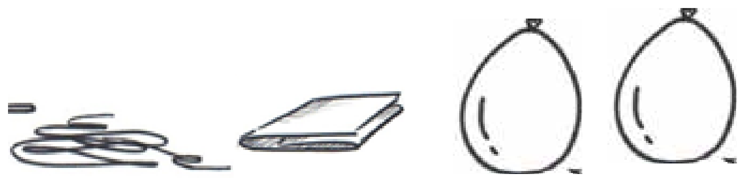
OBJECTIVE

To study forces between electrified bodies.

PREPARATION

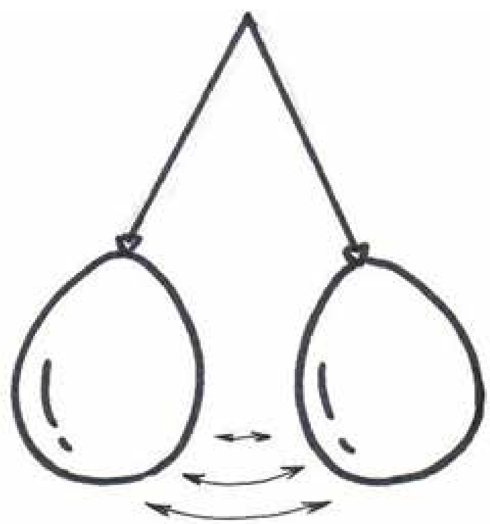
Materials needed:

- Thin string.
- A piece of paper towel or napkin.
- Two balloons.



TASK

1. ***Inflate two balloons.***
2. ***Hold the balloons with a piece of thin string, as shown in the drawing.***
3. ***Rub one balloon with a piece of paper towel or paper napkin or even with your hand.***
4. ***Bring the balloons close to each other.***



RESEARCH QUESTIONS

— What do you notice?

— Why do two balloons of the same kind affect each other?

OBSERVATION

The balloons attract or repel each other.

EXPLANATION

- There is a force between the balloons.
- The force is repulsive.
- Between each one of the rubbed balloons and your hand (towel paper, napkin) an attractive force appears.

2.10. EXPERIMENT 10. MOVING ELEMENTS

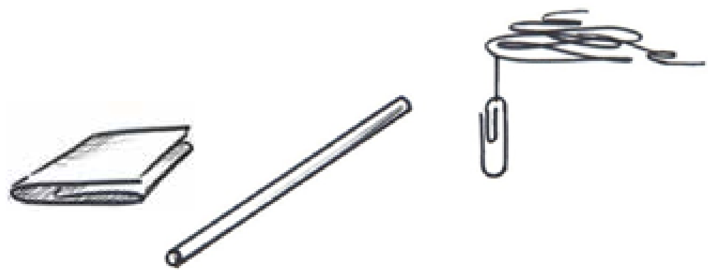
OBJECTIVE

To study forces between an electrified body and a non- electrified body (uncharged body/neutral body).

PREPARATION

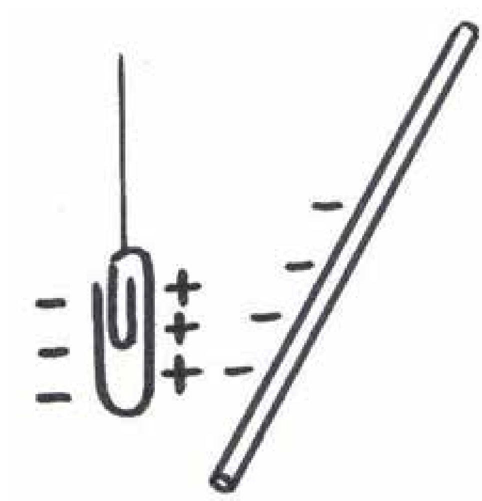
Materials needed:

- A paper towel or napkin.
- A plastic stick.
- A metal paper clip on a string.



TASK

1. ***Rub the plastic stick with a paper towel or a paper napkin.***
2. ***Bring the stick close to the metal paper clip hanging on the string.***



RESEARCH QUESTIONS

— *What do you notice?*

— *Why is the paper clip moving?*

OBSERVATION

EXPLANATION

The paper clip is made of metal and it is neutral. When the rubbed plastic stick (negative) gets close to the neutral paper clip, the electrons of the metal 'run away' to the other side of the clip (and an attractive force appears). The reason is that electrons (negative charges) in metal bodies move freely inside the metal.

2.11. EXPERIMENT 11. A CAN, A PAPER CLIP AND A PLASTIC STICK

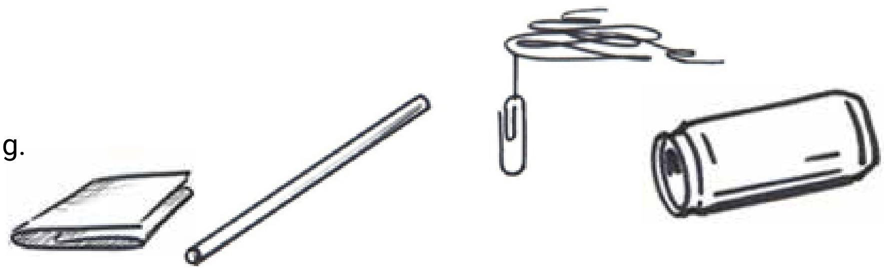
OBJECTIVE

To explain the attraction between and electrified object and a neutral/non charged object.

PREPARATION

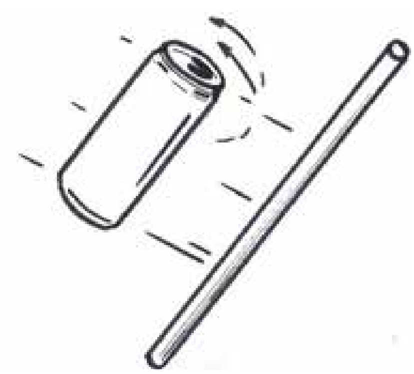
Materials needed:

- A piece of fabric.
- A plastic stick.
- A paper clip on a string.
- An empty metal can.



TASK

1. ***Rub the stick with a piece of fabric.***
2. ***Bring the stick close to the metal paper clip hanging on a string.***
3. ***Bring the plastic stick close to the metal can.***



RESEARCH QUESTIONS

— *What do you notice?*

— *Why is the paper clip moving?*

— *Why is the can moving?*

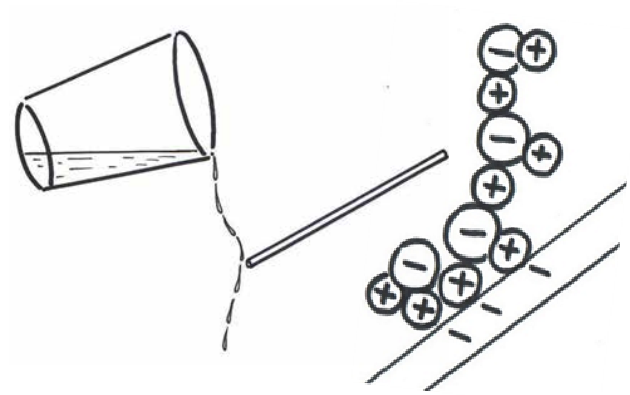
OBSERVATION

EXPLANATION

The same reason. When the rubbed stick is close to each metal body, electrons 'run away' to the other side of the metal can or the metal paper clip, alternatively.

2.12. EXPERIMENT 12. REPEATING EXPERIMENT 4.A

Why does the rubbed stick attract the stream of water? Does the same happen in the case of the pieces of paper, paper clip or the can? The answer is NO. The reason is in the nature of the water molecules. Water molecules are polarized, so the two positive molecules of hydrogen are attracted by the negatively rubbed stick.



To learn more about molecules:

Imagine one drop of water. Now imagine that drop divided into a lot of other tiny drops, and those tiny drops into other smaller tiny, tiny drops, until you get such a small, tiny drop that it cannot be divided any more. You have just obtained a molecule of water.

PRESCHOOL P34 'MALI ODKRYWCY' (BYDGOSZCZ, POLAND).
DISCOVERING COHESION AND ADHESION FORCES

1. COORDINATOR'S INTRODUCTION

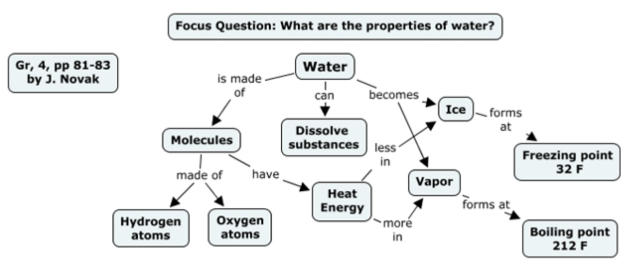
The purpose of the research carried out by the Mali Odkrywcy infant school was for the students to discover the existence of forces that they cannot see with their eyes but which are present in nature: the forces of adhesion and cohesion. To do this, they carried out a series of experiments in which, following the constructivist method and using questions, they began with the characteristics of water, to later experiment and discover how water adheres to other substances (holding water between two fingers and the card experiment), as well as how water in its liquid state stays together, thanks to cohesion forces (the drops on a coin experiment). These facts favoured the introduction of the water molecule concept, which enabled the children to discover the existence of a natural phenomenon: surface tension (the paperclip on water experiment).

This pathway chosen by the teachers marks the beginning of the discovery of the scientific model of water: water molecules are joined together by the forces of cohesion and join to other substances through the forces of adhesion.

2. THE METHODOLOGY COMMON TO ALL THE EXPERIMENTS: NOVAK'S MAP

Beginning in the 1970s, Novak and his research team at Cornell developed the technique of concept mapping as a means of representing the emerging science knowledge of students. It has subsequently been used as a tool to increase meaningful learning in the sciences and other subjects as well as represent the expert knowledge of individuals and teams in education, government and business.

Ausubel believed that the learning of new knowledge relies on what is already known. That is, construction of knowledge begins with our observation and recognition of events and objects through concepts we already have. We learn by constructing a network of concepts and adding to them. Ausubel also stresses the importance of reception rather than discovery learning, and meaningful rather than rote learning.



3. RESEARCH PROJECT: DISCOVERING COHESION, ADHESION AND SURFACE TENSION

3.1. DESCRIPTION OF ACTIVITY 1: LOOKING FOR THE CHARACTERISTICS OF WATER

The title of this activity is Playing with water: discovering the main characteristics of water.

The activities (1, 2 and 3) were carried out in Kindergarten 34 'Little Explorers' in Bydgoszcz. The lead teachers on the project were Beata Zawada and Barbara Krakowska who worked with 25 five- and six-year-olds: 11 girls and 14 boys.

All discussions during the project were based on the Socratic method. This method means teachers ask children a progression of seemingly innocent questions that ultimately lead the respondents to a logical conclusion that is incompatible with the children's originally stated belief.

Material used in the research experiment

Pitchers with water, orange juice in a transparent cup, 2 containers of different shapes, 2 cups (one with vinegar, one with water), a board for summing up the topic, coins, a pipette, a magnetic card, a ruler, a saucer.

Resources used

1. S.Elbanowska. Jak zadziwić przedszkolaka. Tym, co świeci, pływa, lata. W- wa 1994.
2. G.Walter. Woda – żywioły w przedszkolu. Kielce 2004.
3. S.Hewitt. Przygoda z przyrodą – zabawy i eksperymenty. Wyd.Podsiedlik – Kaniowski i Spółka 2000.
4. https://www.aulavirtual.csic.es.
5. http://www.csicenlaescuela.csic.es.

In total the experiment took 24 hours including: Preparation, acquiring the supplies, research, executing the experiment, children drawing pictures about the experiment, conclusion.

Purpose of the research project

The main objective of the project was to learn and consolidate the children's basic knowledge about water. The children conducted experiments with water and learned about the role of water in nature.

Elaboration and preparation of the research activities

First, the teachers studied the topic. The teachers made notes, consulted with each other, planned activities, looked for the necessary materials and made a plan for the order of the activities.

One day before the experiment, the teachers asked the children what water actually is, its smell, colour, and taste. Does water have a shape?

The children gave different types of answers. Some said that water is white or blue, that it tastes like soup, that it is salty, it tastes awful, it has the shape of a jug or a bottle.

The importance of inquiry in research work: The Nature of Scientific Inquiry (NOSI)

Next, the children started experimenting. Each child poured some bottled water into transparent cups. They put pictures behind the cup to check if they were visible. They were. In the next step, the children tasted the water and came to the conclusion that water is tasteless. In the next stage children poured water into different-shaped containers.

Figures 1 and 2.

The teacher asked a question: *What is the shape of water?*

Some children replied that water does not have a shape; some said it has shape of the jug.

Uncovering misconceptions

The teacher poured the water from the jug onto the floor and asked again. The children shouted that *water doesn't have a shape*. The students checked the "shape of the water" by pouring water into different shaped containers.

Figure 3.

Final assessment of the activity

Finally, the children found out the answers to the questions about the shape, taste, smell, and colour, and correctly matched the answers on the board.

DESCRIPTION OF ACTIVITY 2: COHESION AND ADHESION

Material used

The materials used in the research experiment were magnetic card, a pipette, coins, ruler, glasses and, of course, water.

Resources used

1. S.Elbanowska. Jak zadziwić przedszkolaka. Tym, co świeci, pływa, lata. W- wa 1994.
2. G.Walter. Woda – żywioły w przedszkolu. Kielce 2004
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5. http://www.csicenlaescuela.csic.es.

Purpose of the research project

Through experimentation, children find out about the stickiness of water and the forces of adhesion and cohesion. Subsequently, they understand molecular theory. There are some steps in this:

Discovering that cohesion and adhesion forces exist.

Stating the questions that will be established.

Elaboration and preparation of the research activities

The group of teachers went through a series of training sessions conducted by the coordinators in Madrid and Poland. The teachers shared ideas with each other, planned activities, looked for the materials necessary, and guided experiments with children.

One day before the experiment, the teachers showed the students the experiments and asked the children how water is held between the fingers, and why a drop of water does not fall off magnetic card.

Figure 4.

The children gave various answers:

— *Fingers hold the drop of water.*

— *The drop is stuck to the fingers.*

— *The card is stuck to the glass.*

— *Water holds the card.*

Together we started looking for answers by conducting the experiments.

The importance of inquiry in research work: The Nature of Scientific Inquiry (NOSI)

The teachers chose an experiment to awaken the children's curiosity about the topic: holding a drop of water between the fingers.

Observation. Discussion on the topic *Why does water stick to our fingers?*

The children answered:

— *Water sticks to fingers.*

— *The water is glued between our fingers*

It happens because:

— *Water is sticky.*

— *Fingers are sticky.*

— *A drop is very small and light.*

Uncovering misconceptions

To uncover the misconceptions, the teachers introduced another experiment. The students poured a drop of water onto the magnetic card and then turned it upside down. The drop stayed on the card. Why does this happen? Why doesn't the card fall down? The teachers presented forces of adhesion (the tendency of dissimilar particles or surfaces to cling to one another) and cohesion (the tendency of similar or identical particles/surfaces to cling to one another) to the children.

Final assessment of the activity

The children experimented with two coins, one big and one small. With the help of a pipette children put water, drop by drop, onto the surface of the coins. They asked the question: why don't the drops fall off? Why do they stick to each other? The drop does not fall off because of the cohesion and adhesion forces. Adhesion is the tendency of dissimilar particles or surfaces to cling to one another and cohesion refers to the tendency of similar or identical particles/surfaces to cling to one another. Thanks to these forces the drops stick to the surfaces of a saucer, card and ruler.

Students conducting further experiments were able to identify, name, and point to the cohesion and adhesion forces.

DESCRIPTION OF ACTIVITY 3.1: DISCOVERING THE SURFACE TENSION

Materials used

Material used in the research experiment: jugs with water, beakers, pepper, pipette, paper clips, needles, washing liquid, balloons, a pond skater.

Resources used

1. S. Parker. Woda. Eksperymenty i doświadczenia. Warszawa 2006

2. P. Ashbrook. Nauka jest prosta. Kielce 2003

3. U. Berger. Księga eksperymentów. Kielce 2008

4. https://www.aulavirtual.csic.es.

5. http://www.csicenlaescuela.csic.es.

Purpose of the research project

The main objective of the project was to learn and consolidate children's basic knowledge about water. The students found out that water has a "skin", thanks to which some insects, e.g., pond skaters, can stand on the surface of water.

Elaboration and preparation of the research activities

Before the project, the teachers investigated the topic. The teachers made notes, shared ideas, planned activities, looked for the necessary materials and went through the planned activities.

One day before the experiment, the teachers asked children "Will a needle remain on the surface of water?", "Can a paperclip swim?", "Why does a pond skater move on the surface of water?"

Children gave different types of answers. Some said that the needle would sink, some said it would swim; the paperclip swims because it is light; some children believed that the paperclip would sink because it is made of metal; some children thought that the pond skater could walk on water because it has special shoes, it is light, or has big legs.

The importance of inquiry in research work: The Nature of Scientific Inquiry (NOSI)

Next, the children started experimenting. Each student poured some water into a beaker and tried to rest a needle on the water. They observed what happened and drew conclusions. Some children were able to balance the needle, but a small group of children were not able to make the needle float on the surface. Looking at their friends they kept on experimenting.

Figure 5.

Figure 6.

Figure 7.

The teacher asked a question: Why does the needle ‘float’ on water?

Some children replied that it ‘floats’ because it is light or thin, it does not weigh very much and that is why it stays on the surface.

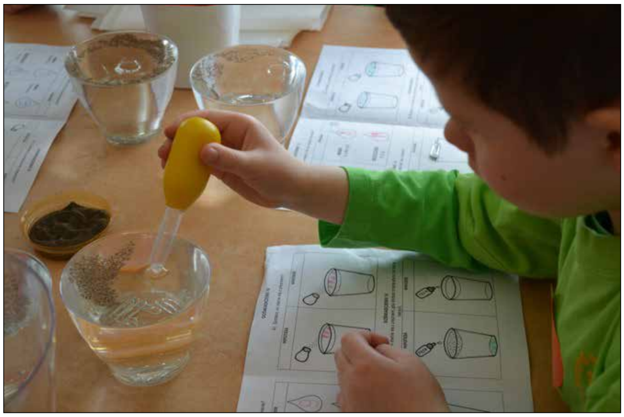


Figure 8.

Uncovering misconceptions

The teachers showed the children an insect, a pond skater, which can ‘walk’ on water. They explained that water has a ‘skin’. It is not very strong. Under the pond skater’s legs we can see the ‘skin’ bending. The teacher showed the students the ‘water skin’ model and explained the experiment.

The next stage of the experiment was to try to put a paperclip on the surface. Not all the children succeeded in completing the task. The teacher suggested using a tool made of a bent paperclip which is used as a ‘spoon’. Thanks to that tool, the children were able to accomplish the task. Each student was successful.

Final assessment of the activity

Once they had accomplished the experiment, the children drew conclusions and shared their observations with their friends and teachers. They understood what surface tension is and could apply it to other situations in their lives (e.g., pepper on water). They kept on investigating…

Figure 9.

DESCRIPTION OF ACTIVITY 3.2: BREAKING THE SURFACE TENSION

Material used in the research experiment

Pepper, washing-up liquid, a balloon.

Resources used

1. S.Elbanowska. Jak zadziwić przedszkolaka. Tym, co świeci, pływa, lata. W- wa 1994.
2. G.Walter. Woda – żywioły w przedszkolu. Kielce 2004.

3. S.Hewitt.Przygoda z przyrodą – zabawy i eksperymenty. Wyd.Podsiedlik Kaniowski i Spółka 2000.
4. S. Parker. Woda. Eksperymenty i doświadczenia. Warszawa 2006.
5. P. Ashbrook. Nauka jest prosta. Kielce 2003.
6. U. Berger. Księga eksperymentów. Kielce 2008.
7. https://www.aulavirtual.csic.es.
8. http://www.csicenlaescuela.csic.es.

Purpose of the research project

Through experimenting, the children revised the fact that water has a 'skin' and that it is not very strong and can be easily broken.

Elaboration and preparation of the research activities

The group of teachers went through a series of training sessions conducted by the CSIC at School team in Madrid and Poland. The teachers shared ideas with each other, planned activities, looked for the materials necessary, and guided experiments with children.

One day before the experiment, the teachers consolidated the children's knowledge about water and asked them whether the skin of water is strong, or if it can be damaged easily.

The children gave various answers: one group claimed that the skin is very strong and elastic and it cannot be broken. The other children believed that it is very thin and can be easily broken. The teacher proposed experimenting to check what the skin of water is like.

Figure 10.

Figure 11.

Figure 12.

The importance of inquiry in research work: The Nature of Scientific Inquiry (NOSI)

The teachers chose an experiment to awaken the children's curiosity about the topic: putting some pepper onto the surface of water.

Observation and discussion on the topic: *What happens to the pepper when we put it on water?*

The children answered:

— *The pepper will go down into the beaker.*

— *The pepper will float.*

It happens because:

— *Water has skin.*

— *It's light.*

— *it's small.*

Uncovering misconceptions

To uncover any misconceptions, the teachers introduced another experiment. The students put some pepper into a beaker. Next, they watched what would happen. After that they added some washing liquid with the help of a pipette.

The teacher asked what happened to the pepper, and why did pepper go to the bottom of the beaker. All the children answered correctly. The water's skin has been broken and damaged.

Final assessment of the activity

As a follow up, the students experiment with coins. They put some coins into the beakers full of water. The teacher introduced the concept of meniscus to students. All the students counted the coins and observed the meniscus. After a certain number of coins had been dropped into the beaker, the water started pouring out. The teacher asked what had happened. All the students answered that the water's skin had broken.

4. FINAL CONCLUSIONS

After conducting further experiments, the students were able to conclude that the 'skin' covering water is not very strong and heavy objects fall to the bottom. Some light objects can be rested on the 'skin' without breaking the surface tension. Finally, they got an analogue model: the water has a skin.

SAN FRANCISCO PUBLIC SCHOOL (PAMPLONA, SPAIN).

DISCOVERING THE FORCES OF ADHESION AND COHESION

1. COORDINATOR'S INTRODUCTION

San Francisco School, in Pamplona, is an example of the bilingual schooling model in Spain, involving Basque and Spanish, and with English taught as a foreign language. It is interesting to see how in this centre, independently of the teaching model followed, science brings together cultures and promotes sexual equality.

In this case, as the students involved were from primary education, the teachers approached the magnitudes implied in the phenomena investigated -adherence and cohesion- not only qualitatively, but also quantitatively. They began by conceptualising the concept of force by experimenting with a paperclip and a magnet. They continued the research process by holding a drop of water between their fingers to discover adherence and cohesion forces. To further conceptualise these forces, they undertook other experiments (the card and drops of water on a coin experiments), utilising suitable language and applying the corresponding laws. Later, using a dynamometer they determined the force of adherence between a glass slide and a CD with a table, in this way moving on from observation to magnitude. As a second phase of investigation, and as an assessment, they introduced an analogue model (observing what happens when a drinks can is taken out of the fridge), which helped the children understand the behaviour of the surface of water, finishing with a dramatisation of the forces of cohesion and adhesion. Through this constructivist path, the children arrived at the molecular model of water and, by observing the macroscopic world which they can visualise with their senses, were able to understand what happens at a sub-microscopic level.

2. METHOD COMMON TO ALL THE ACTIVITIES

Before beginning the research process with the children, a conceptual map was drawn up on the nature of the subject in question, indicating the lowest level required, or Ausubel significance level. The map had a constructivist structure and indicated the experimental path necessary to follow in order to introduce the various concepts. The research was based on the prior level of knowledge (Ausubel level) it was necessary for the children to have.

The students had to understand the following concepts before they began: distance, length, surfaces, and volumes (according to the children's cognitive stage).

States of matter: solid, liquid, gas; changes of state: evaporation and condensation.

The properties of liquids that distinguish them from solids and gases.

The specific properties of water.

What is a force?

Conceptualising a force.

3. DESCRIPTION OF THE RESEARCH PROJECT: DISCOVERING THE FORCES OF ADHESION AND COHESION

Description of the research

The research was carried out in the four classes of the third cycle of primary education (primary classes 5 and 6; ages 9-12), as well as one class from the second cycle (primary class 3; ages 7-9) in both linguistic models used in the school: Basque and Spanish. Of the 95 students who took part 50 used Basque and 45 used Spanish, although the research results were the same with both language models. We consider it important to state that the 45 students using the AG (Spanish) model are socially disadvantaged children, with a low IESC (Index of economic, social and cultural status) level, some of whom were unfamiliar with the vehicular language (Spanish), and some of whom exhibit disruptive behaviour and absences from school.

The 50 students following the D (Basque) model are from normalised families, and do not display absenteeism or disruptive behaviour. These children have a medium-medium/high IESC level.

We also consider it important to state that no significant differences were observed between the sexes: the balance of the whole was approximately 50/50 and both girls and boys participated in the experiments proposed. The sessions took place during the school term and the teachers involved were those who teach science subjects. The experiments were carried out in mixed-level groups including children aged 7-12. This allowed the older children to help the younger ones and, at the same time, the younger ones motivated the older ones. All the children were very motivated throughout the research.

The full title of the research was: *What is the world made of?* Describing the forces of adhesion and cohesion in the case of water, and applying simple molecular theory to explain them.

Goal of the research

Our main goal was to follow the path that leads from the discovery of cohesion and adhesion forces up to the molecular theory of matter as applied to water. This involved discovering "what the world is made of" by observing the behaviour of adhesion and cohesion forces in water.

The questions established in the research pathway were:

- *What type of forces are responsible for the forces of cohesion and adhesion?*
- *What other processes do they appear in?*
- *Are there any laws that summarise the behaviour of water in relation to these forces?*
- *To respond to these questions we had to think about experiments whose results would allow us to find out the answers (questioning method).*

- *What experiments can we carry out to answer these questions?*

- *What is water really like at a sub-microscopic level?*

Resources used

The resources used in this activity were: droppers, water, cards, paperclips, coins, a magnet, drinks cans, dynamometers, glass slides, CDs.

The basic literature used was the CSIC virtual classroom (www.aulavirtual.csic.es) which contains the training content offered at the beginning of the project, and the CSIC at school website (www.csicenlaescuela.csic.es).

Description of the research pathway. What is the world made of? Describing the forces of adhesion and cohesion in the case of water, and applying simple molecular theory to explain them

We followed a constructivist path through which, by carrying out various successive, related experiments, we observed a natural phenomenon that allowed us to investigate further.

Firstly, we conceptualised the force in order to discover the children's prior knowledge, introduce new concepts (the forces of adhesion and cohesion), and assess this knowledge by carrying out other experiments at the same time as introducing measurement.

Part one: observing a natural, everyday process

Taking advantage of a rainy day, the children observed a natural phenomenon: raindrops on the window. Then, we asked the following questions:

- *What are the drops like?*

- *Why are they spherical?*

- *How to they stick to the window?*

- *Why do they run down?*

Next, we started our science notebooks. When the children had realised, on their own, that the drops were always round/spherical, they wrote this down in their science notebooks. The notebook also favoured the development of other skills, such as linguistic competence as they had to describe the phenomenon they observed.

EXPERIMENT 1. CONCEPTUALISING THE FORCE: INTRODUCTION TO THE CONCEPT OF FORCE - MAGNET AND PAPERCLIP.

The experiment consisted of putting a magnet near a paperclip tied on to a thread and holding it in the fingers, as indicated in the photograph. When the clip was released, it was attracted by the magnet and moved through the space until it stuck to it. If the magnet was moved away, the clip fell to the ground, due to the force of gravity.

The teachers asked the students what forces were acting on the clip. The students gave different answers.

Some gave the correct answer but others did not know what was happening. The reality is that two forces are acting: gravity and magnetism. Both are forces that act at a distance, since neither the Earth nor the magnet are in contact with the clip. In contrast, the thread acts on the paperclip through contact, just like their fingers do on the thread. When the clip is still, it is because the forces of gravity (weight), magnetic attraction and thread are balanced, giving a null result.

As we are dealing with primary school students in this case, we can go as far as discovering that force is a vector magnitude which produces movement (acceleration) in bodies. When a body is at rest is because the sum of the forces acting on it is null.

EXPERIMENT 2. EVALUATING PRIOR KNOWLEDGE: HOLDING A DROP OF WATER BETWEEN THE INDEX FINGER AND THUMB.

The children were asked to describe the experiment using their own words. In this way, we discovered their level of prior knowledge and the existence of any misconceptions. These misconceptions must be deconstructed through experimental methods.

We applied the concept of contact forces to the processes of cohesion and adherence, even though students had not yet been told the names of these forces, which they described as:

Forces of cohesion: the forces that bind the parts of a material together, for example, a drop of water to another drop of water.

Forces of adhesion: the forces that appear between two different materials, such as those that stick a drop of water to the skin of the fingers. This occurs when we adhere a drop of water to another material.

Description of the experimental results: the children described the observed results:

— *The drop of water sticks to the skin of the fingers.*

— *The drop of water does not break, but behaves like an elastic body.*

The new concepts introduced to the children were: the force of adhesion is what appears between the water and the skin. The force of cohesion is that which appears between one part of the water and another.

EXPERIMENT 3. ASSIMILATING THE FORCES OF COHESION AND ADHESION

The students must understand the existence of two forces acting in opposite directions. When the drop gets too long, the adhesion forces that hold it to the fingers are greater than those of cohesion and the drop splits in two. The two halves are attached to the two fingers.

In this way, we state the two laws that govern the behaviour we have observed:

First law: water droplets have a tendency to stick to the surfaces of solids, due to the force of adhesion.

Second law: the drops of water, or parts of a drop, tend to bind to one another through cohesive forces.

EXPERIMENT 4. EVALUATING THE KNOWLEDGE ACQUIRED: THE DROP AT THE TIP OF A DROPPER

This experiment consisted of filling a dropper with water and slowly pressing the rubber bulb so that the drop could be seen to increase in size and stretch until it detached from the tip of the dropper.

What can we see? The children's answer was immediate: it changes shape and size.

We keep investigating: does the same thing happen with other liquids? Why does it fall off?

It is a competition between the forces of adhesion, which keep the drop attached to the dropper, and the forces of gravity, which tend to make it fall off.

EXPERIMENT 5. FORCES BETWEEN THE SURFACE OF A MATERIAL AND A LIQUID

Before the experiment, the children were asked a question:

What do the forces of cohesion and adhesion depend on?

The children gave different responses. We checked that the magnitude of the adhesion forces between a liquid and a solid depend on the type of material in question. To do this, in this experiment we used a drop of water and flat surfaces of different materials: copper, plastic, a drinks can, window glass, and so on. The children saw that, depending on what the surface is made of, the drop behaves differently and acquires different shapes.

The shape they acquire in equilibrium depends on the magnitude of the cohesion forces and the forces adhering it to the surface. If these did not exist, the drop would be perfectly spherical. If there were no cohesion forces, the water would completely adhere to the surface, becoming flat.

Depending on the nature of the surface material the drops take on different shapes.

EXPERIMENT 6. SEMI-QUANTITATIVELY DETERMINING THE MAGNITUDE OF THE ADHESION FORCES AND RELATING THESE TO THE MAGNITUDE OF THE COHESION FORCES

This experiment consisted of observing the shape of the drops and correlating this shape with the angle it is necessary to tilt the surface so that the drops begin to slide under the effect of gravity. The flatter the drop appears, the more important the forces of adhesion to the surface are with respect to the cohesion forces, and the more the plane has to be tilted so that the drop begins to slide downwards.

EXPERIMENT 7. DROPS OF WATER ON A COIN

The students must use the knowledge acquired from this experiment, correctly using the words (concepts) and applying the corresponding laws.

The experiment consisted of placing a coin on a table and using a dropper to, very slowly, place drops of water on its surface. All the children must use the same type of coin (50 euro cents, for example), and clean it with soap and water before beginning the experiment. Using the dropper we put water on drop by drop and observed what happened; at the same time we counted the drops. We reached a point where the water became quite voluminous and even bulged out a little around the edges without spilling off.

What is happening? How is this possible?

We used a magnifying glass to help us look at the shape of this huge drop of water that had formed on the top of the coin. When the children had put on a sufficient amount, the children's attention was drawn to the shape the water was acquiring (some students had already pointed this out). They noticed the spherical form the water was adopting on the coin.

The students were instructed to put a few more drops on. Everyone crouched down, bringing their eyes to table height and observing the shape of the water. They described it as a very flattened drop. At some point the water bulged out from the edge of the coin but did not yet spill off. Finally, when too many drops had been put on, the forces of cohesion between the edges of the coin and the water could no longer support the weight of the deformed water drop and it spilled off.

We used a magnifying glass to help us look at the shape of the huge drop of water that had formed on the top of the coin.

Figures 1 to 4. Experiment 7.

EXPERIMENT 8. A NEW MAGNITUDE: SURFACE TENSION. THE CARD ON THE GLASS OF WATER

This experiment consisted of filling a transparent glass or plastic cup right up to the top and, very carefully, placing a plastic card (like a credit card or hotel key card) on it so that the upper surface did not get wet. Half of the card was placed inside the glass, in contact with the water, while the other half was outside the circumference of the top edge.

The experiment consisted of placing tiddlywink counters or one euro cent coins on the outer part of the card, and observing what happened to the surface of the water that was stuck to the card.

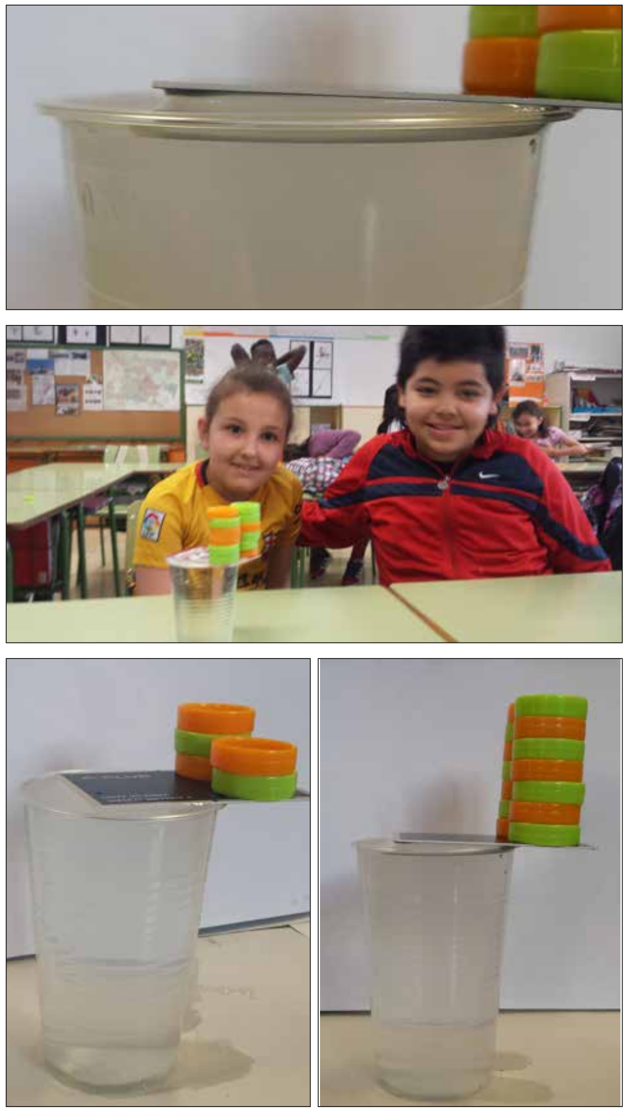
This set up acts like a balance, where one weighing pan is the outer part of the card onto which we place weights, while the other part of the card remains stuck to the liquid thanks to the forces of cohesion between the card and the water.

The surface of the water becomes deformed and resists breaking, behaving as an elastic surface, like a trampoline that you can jump on.

At this point, we can give a name to the observation the children have just made. The behaviour that causes that the surface to stretch and deform as if it was rubber, and which prevents it breaking is known as the surface tension of the liquid. It is due to the force of cohesion between various parts of the surface of the liquid.

The number of coins or tiddlywink counters necessary for the card to fall off, breaking the surface of the water (in other words, overcoming the surface tension), gives us an idea of its magnitude. By counting the coins or counters needed to overcome that force, we introduce a quantitative measurement.

In this way the children arrived at an analogical model: the water behaves as if it had a kind of elastic skin surrounding it; this is responsible for the behaviour of its surface.



Figures 5 to 8. Experiment 8.

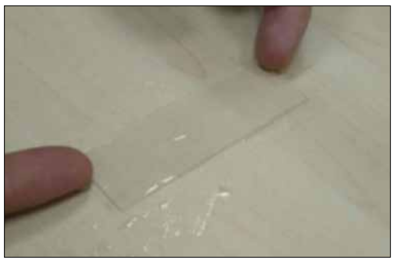
EXPERIMENT 9. QUANTITATIVE MEASUREMENT OF SURFACE TENSION: THE FORCE BETWEEN A GLASS SURFACE AND THE SURFACE OF A TABLE

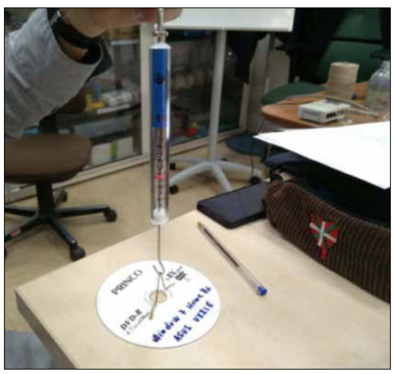
The following experiment is a continuation of the previous one. The idea is to measure the force more precisely. We poured water onto a table so that a very thin moist surface formed. On this we placed a microscope slide or glass square with smooth surfaces and known dimensions.

Next, we tried to separate the glass from the table, observing that this was very difficult, as a force had appeared between the two surfaces that did not exist when there was no water.

We can measure the force between two flat surfaces joined together by a thin sheet of water.

We used a dynamometer (we took this opportunity to introduce the instrument for measuring force) to determine the force with which the glass was sticking to the table, and imagine how the surface of the water sticking them together deformed: in a similar way to how the surface of the water joining the credit card to the water in the glass deformed in the previous experiment.





Figures 9 and 10. Experiment 9.

PART TWO: FINAL EVALUATION. ELABORATING A THEORETICAL MODEL TO EXPLAIN THE BEHAVIOUR OF WATER IN CONTACT WITH SOLID SURFACES: MOLECULAR THEORY

We now introduced an analogue model to help us understand (explain) the behaviour of the surface of the water: the elastic skin model.

We placed a very cold drinks can on a plate and observed that it became covered with drops of water that slid down the surface and formed a pool in the plate.

It was as if the water in the atmosphere, from the evaporation of the sea, puddles, swimming pools, drying clothes, our breathing, and thousands of similar processes, came out of the air.

But we cannot see the water that is in the air. How is this possible? The children had to admit that the water in the air must be in the form of drops so tiny that we cannot see them. The smallest droplet of water in the air is what we shall call a molecule. We can represent these molecules however we like, for example, as very small balls.

This led us to formulate a hypothesis in the form of a water model: water is made up of very small sub-microscopic balls that we cannot see with the naked eye; these attract each other (cohesion) and are attracted to surfaces (adhesion).

We needed to test our theoretical model and use it to try and explain some of the experimental results obtained in the first part.

For example, to do this for the coin and water drop experiment, we used a surface (like an upside down box, or a table) and we defined each student as a molecule and the box as the coin.

The first drop, got onto the box comfortably, so did the second and third drops. The fourth drop had more difficulty but was held on by its companions. The fifth drop could not get on and, in addition, made the others fall off.

This dramatisation established the model of what it happens at a microscopic level on the coin when we drop water onto it.

The students were invited to explain what had happened using the model they already had. Their answer was that the forces of cohesion (between each other) and adhesion (with the surface of the table) were acting. Each student modelled how they behaved like the water molecules that stick to one another other (cohere) forming the drop on the surface of the coin until there is a stronger force (in this case the weight of the drop itself) that makes the water spill off.

The theoretical model worked. It helped the children imagine what happens at a sub-microscopic level, and therefore explains the behaviour of the macrocospic world we perceive with our senses. We provisionally accepted this as our scientific model, which we will keep working on.

Figure 11. Atom model.

‘ASUNDUSE LASTEAED’ PRESCHOOL (TALLIN, ESTONIA).

FROM SUGAR TO ELECTRICITY

1. COORDINATOR’S INTRODUCTION

The activities carried out by the Estonian Educational Centre TALLINA ASUNDUSE LASTEAD are based on a pedagogical model that allows young students in early stages of education to investigate certain natural phenomena. To do this, they used water as an everyday element to discover some laws of the molecular model of matter. The initial experiment consisted of dissolving sugar in water to prove that although the sugar has dissolved in the water it has not disappeared, because we can taste it to check that the sugar is still there. The next step was observational, leaving the glass of water and sugar for a few days, so that sugar stayed in the glass while the water did not. At these ages, children already know that things do not disappear on their own, and they end up accepting that the water that was in the glass has gone into the air, although they did not see this This is the start of discovering changes of state and introducing the concept of molecule.

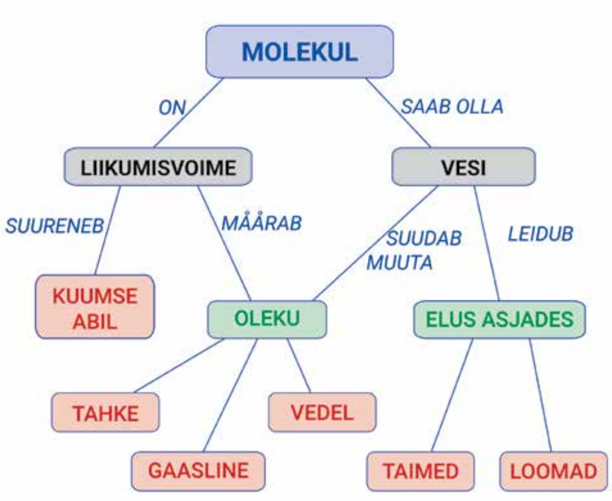
Further research these children carried out involved electrostatic phenomena. They began with a very simple experiment, rubbing a balloon and putting it close to their hair. The idea was to discover the appearance of a force of attraction, in other words, electricity, and begin down the path to discovering its laws. Through this experiment the teachers wanted the children to find out, once again, how to observe the things our eyes do not see. In the first case this was the molecules, and in this second example it was electric charge .

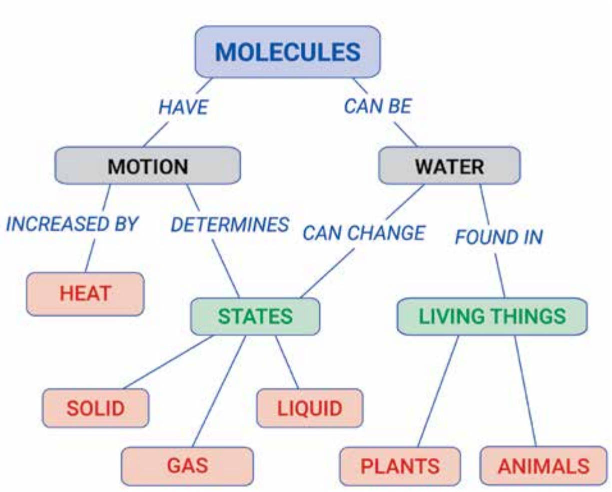
It is interesting, in this work, to observe how the children represent the molecules prior to doing the research (as monsters, flowers, and so on), and how they do this after carrying out the research (according to the model of ‘little balls’ that come together to form liquid water and separate when they evaporate). In this way, these children aged between 5 and 7, show they are capable of visualising things they cannot see, through the mental representations of the models that make up the world around them.

2. DESCRIPTION OF THE METHOD USED IN THE RESEARCH PROJECT

Beginning in the 1970s, Novak and his research team at Cornell developed the technique of concept mapping as a means of representing the emerging science knowledge of students. It has subsequently been used as a tool to increase meaningful learning in the sciences and other subjects as well as represent the expert knowledge of individuals and teams in education, government, and business.

Ausubel believed that learning new knowledge relies on what is already known. In other words, the construction of knowledge begins with our observation and recognition of events and objects through concepts we already have. We learn by building a network of concepts and adding to them. Ausubel also stressed the importance of reception over discovery learning, and meaningful over rote learning in the sciences and other subjects as well as represent the expert knowledge of individuals and teams in education, government, and business.





3. RESEARCH PROJECT 1: WHERE HAS ALL THE SUGAR GONE?

Description of the activity

The experiment took place in Tallinn's 'Asunduse' kindergarten for preschoolers aged 5-7.

The experiment was conducted by the teachers Eneli & Kristel. In total there were 11 children, 6 boys and 5 girls.

Resources used in the research experiment: sugar cubes, cold and hot water, glass jug, spoon, plastic cups, polystyrene foam packing peanuts in 2 different colours.

Literature used:

1. Murulaid, R., Piirsalu, E., Vacht, P., Vaino, K.; Loodusõpetus 7. klassile; [2016]; Estonia.

2. Available online: http://opik.fyysika.ee/index.php/book/view/21#/section/8604

3. Tännan, M.; Loodusõpetus 7. klassile. Sissejuhatus füüsikasse ja keemiasse; [2010]; Estonia.

4. CSIC Virtual Classroom: https://www.aulavirtual.csic.es.

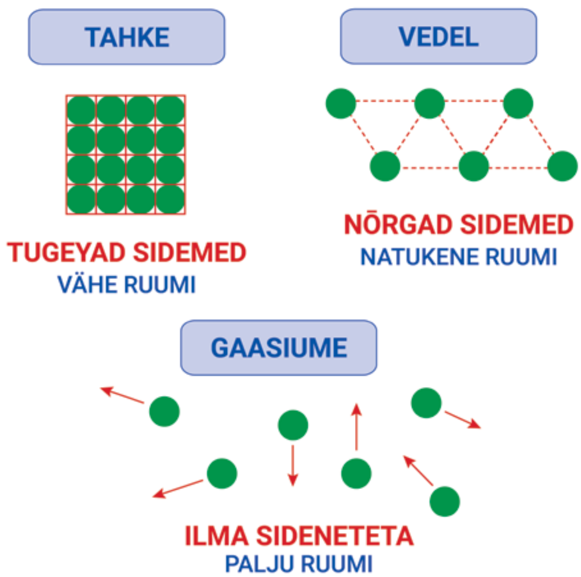
5. CSIC at School: http://www.csicenlaescuela.csic.es.

All discussions held during the project were based on the Socratic method. This method involved the teachers ask a progression of seemingly innocent questions that ultimately led the respondents to a logical conclusion that was incompatible with their originally stated beliefs.

In total, the experiment took 24 hours including: preparation, acquisition of the supplies, research, execution of the experiment, the children drawing pictures of the experiment, and conclusions.

Purpose of the research

The purpose of the research project was to discover molecules, research their nature, and arrive at molecular theory.



Elaboration and preparation of the research activities

First, the teachers studied the topic. They made notes, consulted with one another, planned activities, looked for the necessary resources and decided upon the order of the planned activities.

The day before the experiment, the teachers asked the children what they thought the world was made of and how molecules could be connected to that. The teachers asked the children to draw a picture of this.

On the day of the experiment, the teachers went to the classroom of the group beforehand to set out all the resources required and get the children excited about starting the activities.

The children had not heard about molecules before. Some of the children thought molecules could be monsters and one of the children say that molecules might have teeth.

The Nature of Scientific Inquiry (NOSI)

1. **Observation**. Discussion on the topic *What happens when we add sugar to a jug filled with water?*

   Children:

   – *The sugar melts inside the water.*

   – *Water melts everything.*

   – *No, it does not melt everything. The table does not dissolve.*

   – *It is different in cold versus warm water.*

   – *Water becomes sweet. The water became a rock.*

   – *Cold water does not go sweet. The taste is different.*

   – *The sugar does not get lost.*

2. Experimentation

The children put sugar cubes into cold water. One child stirred the water with spoon. *What happens?*

Children:

- *When we stir it, we have to stir it for 50 hours before the sugar melts.*
- *No, it is not taking so long.*
- *Now some of the sugar has gone already.*

Figures 1 and 2. They put sugar cubes into the water.

The children added boiling water to the cold water. One child stirred it with the spoon. What happens? Children:

- *Some small pieces.*
- *I can't see it.*
- *Where did it go?*
- *It evaporated away.*
- *Now the sugar goes away much faster.*

Figure 3. We can't see sugar in the water.

3. Summary of the results

After doing the experiments and leading the children along the path the teachers wanted, they began a discussion on the topic: *Molecules, what are they? How do they move?*

- A molecule is the smallest unit of a substance that has all the properties of that substance. For instance, a water molecule is the smallest unit that is still water.
- Hot water molecules move faster than cold ones.
- Sugar is less dense than water.
- This type of liquid solution is composed of a solid solute, which is the sugar, and a liquid solvent, which is the water. As the sugar molecules spread evenly throughout the water, the sugar dissolves.

How do molecules move in water or in sugar? Let's try! The research continued…

What do molecules look like if we add some sugar into a jug filled with water?

4. Hypothesis

Children:

— *The sugar is still in the water* —one child had no idea what could happen.

5. Testing the hypothesis in the lab

How can we be sure that the sugar is still in the water? Let's smell it and taste it!

Figure 4. Solid (like a sugar cube).

Figure 5. Liquid (like water).

Figure 6. Sugar

Figure 7. Tasting the water.

- The children smelled the plain water. *How does it smell?*

Children:

 – *It smells like water.*

 – *It smells ordinary.*

- The children tasted the water. *How does it taste?*

Children:

 – *It has no taste.*

 – *I like how it tastes.*

 – *There is no taste at all.*

 – *The water has its usual flavour.*

- The children smelled the sugar water. *How does it smell?*

Children:

 – *It still has no smell.*

 – *Nothing has changed.*

- The children tasted the sugar water. *How does it taste?*

Children:

 – *This is so sweet.*

 – *This is too sweet.*

 – *The sugar is still there.*

6. Explanation provided for the hypothesis

The children gave a series of explanations for why the sugar had not disappeared, a fact which they had proven by testing it beforehand:

 – *Sugar changes from solid to liquid.*

Figure 8.

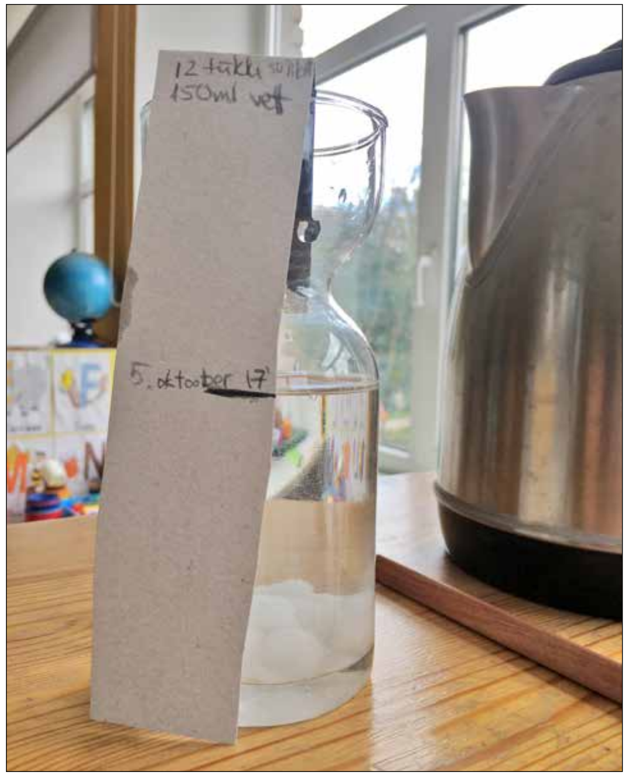


Figure 9.

— *The sugar cubes came apart.*

— *The sugar melted and came to the surface.*

— *The sugar remained in the water.*

— *The sugar particles are so little that we cannot see the sugar.*

Final assessment of the activity

To see whether the sugar was in the water or not, we left a jug containing 150 ml of water and 12 sugar cubes to stand on a shelf.

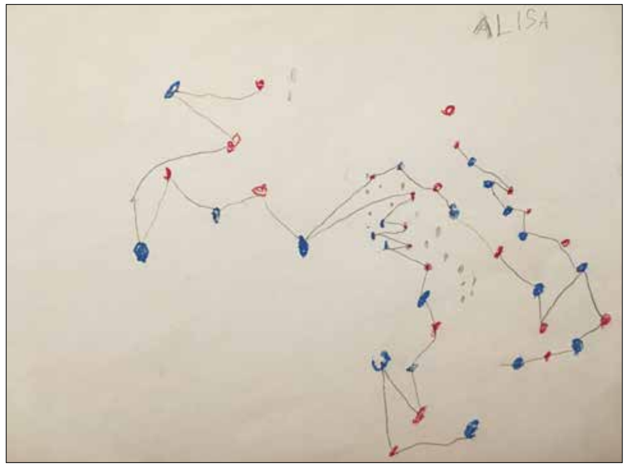
The children watched the water in the vase evaporate on a daily basis, and waited for the final result.

One day after the experiment had been set up, the teachers asked the children what the world was made of, in their opinion, and how molecules could be connected to that. The teachers asked the children to draw pictures of their ideas.

5 of the children were in the kindergarten on each of the days the experiment took place (on the 1st day the children drew a picture before they had learned anything, on the 2nd day the children took part in the experiment, on the 3rd day the children drew a picture with new knowledge on the topic).

The children understood that molecules are very tiny –so small that we are not able to see them with our eyes.

Finally, they had arrived at the molecular model.



Figures 10 and 11. Drawing of experiment and molecules by students.

4. RESEARCHING PROJECT 2: DISCOVERING STATIC ELECTRICITY

Purpose of the research

The purpose of the research project was for children to discover, through experimentation, static electricity.

Description of the activity

Resources: balloons, labels (+ and – signs).

In total, the experiment took 24 hours including: preparation, acquisition of the supplies, research, execution of the experiment, the children painting pictures of the experiment, and conclusions.

The experiment took place in Tallinn's "Asunduse" kindergarten for preschoolers aged 5-7. The experiment was conducted by the teachers Eneli & Kristel. In total there were 13 children, 8 boys and 5 girls.

Just as in the previous project, all discussions used the Socratic method.

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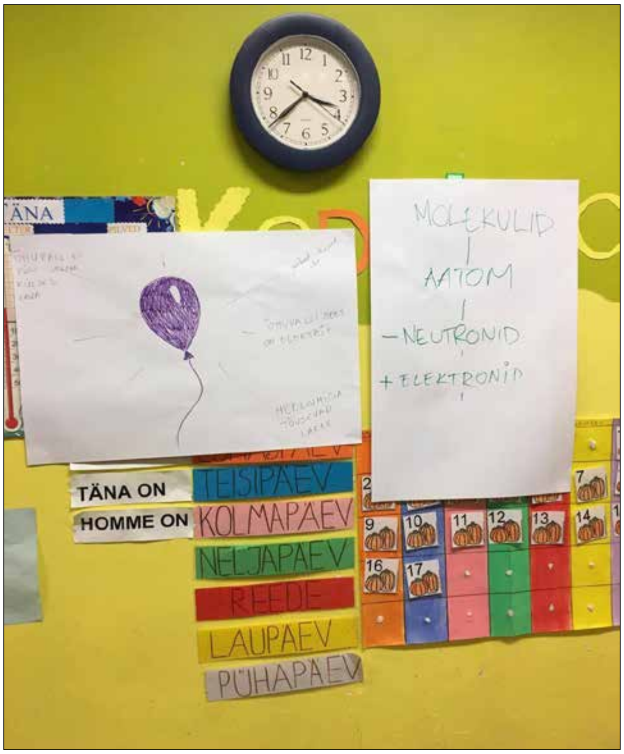
Elaboration and preparation of the research activities

First, the teachers studied the topic. They made notes, consulted with one another, planned activities, looked for the necessary resources, and decided on the order of the planned activities.

The day before the experiment, the teachers asked the children what happens when you rub a balloon against your hair. Teachers asked the children to draw a picture of their ideas.

On the day of the experiment, the teachers went to the classroom of the group beforehand to set out all the resources required and get the children excited about starting the activities.

Because of the sugar experiment they had done before, the children remembered some things about molecules and their meaning.



Figures 12 to 14.

The Nature of Scientific Inquiry (NOSI)

1. Observation

Discussion on the topic: what happens when we rub balloon against our hair?

In this activity the children discover that a force appears between the balloon and our hair. This force, which is electric, makes the children start talking about why the materials are attracted to one another, when we rub one of them.

2. Experimentation

To investigate this phenomenon we carried out a series of experiments that helped us discover the laws of electricity.

As a class, we commented on the fact that this force of attraction between the balloon and the hair appears because there is another, different force, and that is why they are attracted (introducing a new concept: attraction).

3. We started the research. Hypothesis and checking

We started to investigate: each child got a label with a sign on to experiment with, and to begin to conceptualise the idea of positive and negative charges and their representation using the + (positive) and - (negative) signs. They acted out the fact that children with different signs were attracted to one another and those who had the same sign had to repel each other.

Later, the children took the balloon to a wall and found that it ‘stuck’ to it.

The children said:

— *Our hair is going up to the balloon.*

— *There is a little bit of electricity in the balloon.*

— *Air.*

— *Why is my hair getting dirty?*

— *How does the electricity get into the balloon?*

After a class discussion, we reached some conclusions: charges of the same sign are repelled and those of different signs are attracted. In this way it was easy to discover the laws of electricity.

Figures 15 to 17.

4. Final evaluation of the activity

We asked the children to do further experimentation at home. This involved doing more electrostatic experiments where they could see the same phenomena they had already observed.

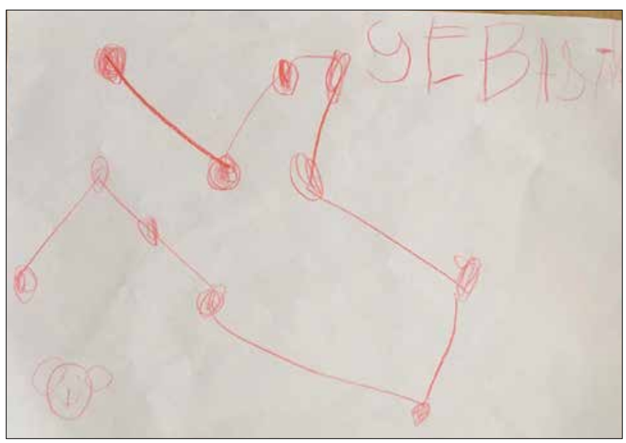
We asked them to rub a balloon again, but this time put it close to a stream of water. We checked that the water was attracted to the balloon.

The children came to school after the home experiment and described what had happened. Some of them asked us ‘Why?’ ‘But how can water zigzag?’ Others noticed that the same thing happened as with the balloon and their hair.

In total, there were 6 children in the kindergarten for the 3 days (on the 1st day the children drew a picture before they had learned anything, on the 2nd day the children took part in the experiment, on the 3rd day the children drew a picture with new knowledge on the topic).

Finally our conclusions are that children understand that:

1. There are different electrical charges and these obey certain laws.
2. That they are part of the world that our eyes cannot see.
3. However, to understand the balloon and the stream of water experiment, it is necessary to continue researching, because they need to discover that the water molecules are polar, in other words, they have a positive and negative charge.



Figures 18 to 20.